Washington State
Department of Transportation

SR 8 MP 3.16 Unnamed Tributary to Wildcat Creek (WDFW ID 993724): Final Hydraulic Design Report

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1 Introduction

To comply with United States et al. vs. Washington, et al. No. C70-9213 Subproceeding No. 01-1 dated March 29, 2013 (a federal permanent injunction requiring the State of Washington to correct fish barriers in Water Resource Inventory Areas [WRIAs] 1 through 23), the Washington State Department of Transportation (WSDOT) is proposing a project to provide fish passage at the State Route (SR) 8 crossing of Unnamed Tributary to Wildcat Creek at milepost (MP) 3.16 within WSDOT's Olympic region. The existing structure at that location has been identified as a fish barrier by the Washington Department of Fish and Wildlife (WDFW) and WSDOT Environmental Services Office (ESO) (site identifier 993724) and has an estimated 1.4 miles of habitat gain.

Per the federal injunction, and in order of preference, fish passage should be achieved by (1) avoiding the necessity for the roadway to cross the stream, (2) use of a full-span bridge, or (3) use of the stream simulation methodology. WSDOT evaluated design options as defined in the injunction. Avoidance of the stream crossing was determined to not be viable given the location of the highway and the need to maintain this critical transportation corridor. WSDOT is proposing to replace the existing crossing structure with a bridge structure design based on the confined bridge criteria methodology.

The crossing is located in Grays Harbor County, 3.25 miles Northeast of Elma, Washington in WRIA 22. The highway runs in a northeast–southwest direction at this location and is about 470 feet from the confluence of the unnamed stream with Wildcat Creek. Unnamed Tributary to Wildcat Creek generally flows from east to west beginning 0.9 miles upstream of the SR 8 crossing (see Figure 1 for the vicinity map).

The proposed project will replace the existing corrugated steel pipe, which is 204 feet long and 4 feet in diameter, with a structure designed to accommodate a minimum hydraulic width of 17 feet. The proposed structure is designed to meet the requirements of the federal injunction using the bridge design criteria as described in the 2013 WDFW *Water Crossing Design Guidelines* (WCDG) (Barnard et al. 2013). This design also meets the requirements of the WSDOT *Hydraulics Manual* (WSDOT 2022a).

The channel bed for this unnamed tributary is expected to naturally regrade 0.5 to 2.5 feet below the constructed surface over time. The regrade will occur at some time in the future when an existing, private culvert downstream is replaced or removed.

The original Preliminary Hydraulic Report for this site was completed in 2019 by a different engineering group. The requirements and organization of this document have since changed. This Final Hydraulic Report has updated the preliminary work to the extent practical using provided existing condition information from the earlier work on this site. The preliminary data does not always provide the level of detail that is now expected for fish passage work, and so this report may not contain all the information that is provided in more recent reports.

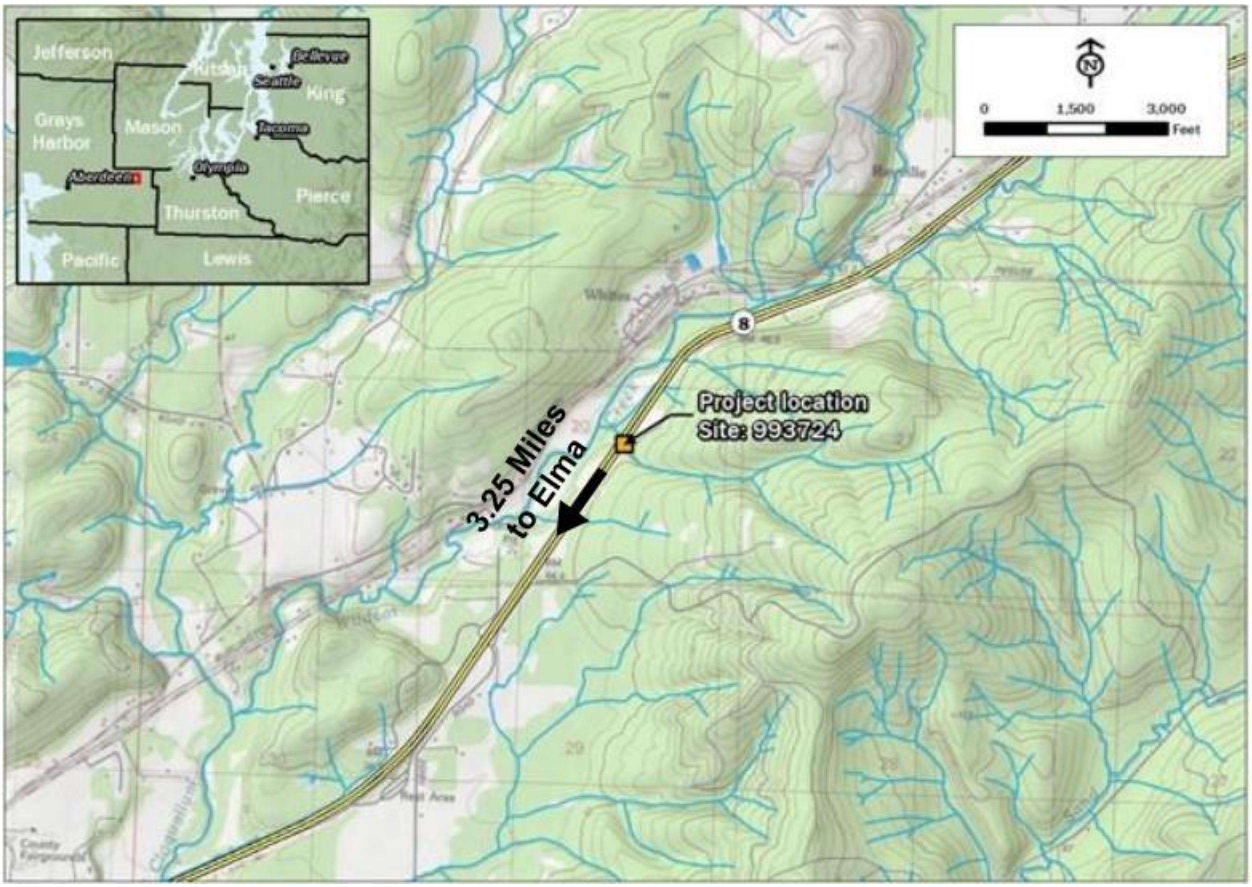


Figure 1: Vicinity Map

2 Watershed and Site Assessment

The existing watershed was assessed in terms of land cover, geology, regulatory floodplains, fish presence, site observations, wildlife crossing priority, and geomorphology. This was performed using a site visit and desktop research with resources such as the United States Geological Survey (USGS), Federal Emergency Management Agency (FEMA), WDFW, and past records like observations, maintenance, and fish passage evaluation.

2.1 Site Description

The culvert under SR 8 at MP 3.16 (Site 993724) for the Unnamed Tributary to Wildcat Creek is listed as a barrier due to excessive slope. The culvert drops roughly 7 feet over 200 feet, resulting in a slope of 3.4 percent. The downstream end of the culvert has a few inches of built-up sediment along the bottom. This crossing is not listed as a Chronic Environment Deficiency (CED) or failing structure (WSDOT, 2020).

WDFW estimates 7,444 feet of potential habitat would be accessible upstream of Culvert 993724 if fish passage is restored at the SR 8 crossing. The potential habitat gain would only benefit resident species until the downstream barrier, a second culvert referred to in this document as the “Forest Culvert,” is also corrected. The significant 3.9-foot hydraulic drop at the Forest Culvert outlet renders the entire project reach and areas upstream of SR 8 currently inaccessible to salmonids.

2.2 Watershed and Land Cover

The watershed area for the Unnamed Tributary to Wildcat Creek upstream of the SR 8 crossing is entirely forested (Figure 2). On the downstream (west) side of SR 8, there are indications of other land use in the past. A barbed wire fence and second culvert were encountered near Culvert 993724 within the immediate downstream area. Land use in this area is now mostly forested and overgrown. As the unnamed stream nears the confluence with Wildcat Creek, the land cover transitions from forest to forested wetland. The forested wetland borders a residential area where the land has been cleared. The watershed land elevations range from 100 to 200 feet above sea level and generally slope from east to west. A land cover map and table were not included in the original PHD.

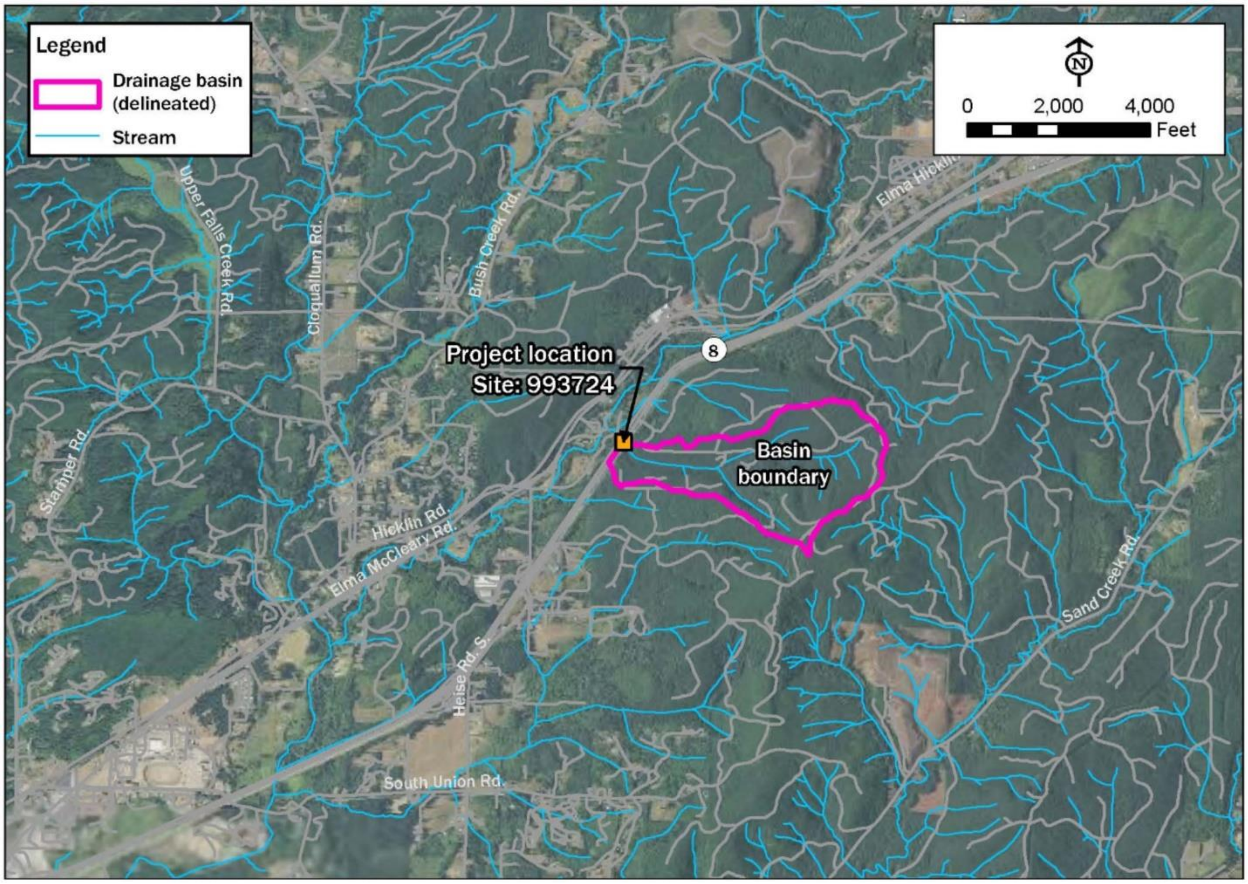


Figure 2: Watershed Map

2.3 Geology and Soils

The unnamed stream's watershed lies primarily within Tertiary Period, Miocene Epoch marine sedimentary rocks of the Montesano Formation (unit "Mm2m" on Figure 3). This formation is found at higher elevations throughout Grays Harbor County. The watershed is just south of the mapped extent of the continental ice limit during the Pleistocene and was not covered by glacial sediments. The only variation in surface geology occurs where the gradient drops at the SR 8 crossing and near the confluence with Wildcat Creek. In this area the surface consists of undifferentiated Quaternary era alluvium, indicating the upstream extent of an alluvial fan. The area of alluvial deposits coincides with the area classified as Zone A floodplain by FEMA.

Soils in the watershed are of a consistent character, reflecting the uniformity of the underlying geology. The soils are loams and silt loams that differ in map unit name by slope expression (Figure 4). All soils have moderate to high infiltration rates, falling into the same hydrologic soils group, Group B (Table 1).

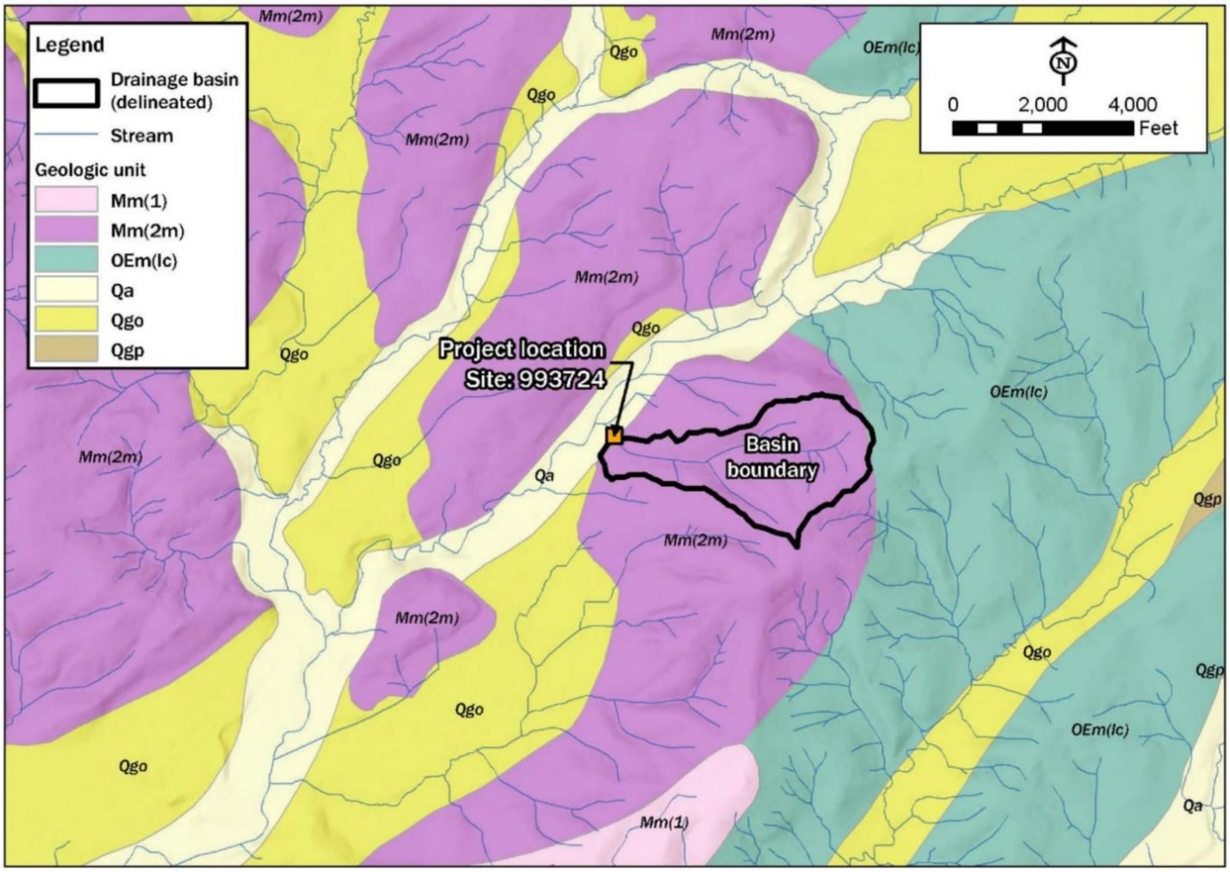


Figure 3: Geologic Map

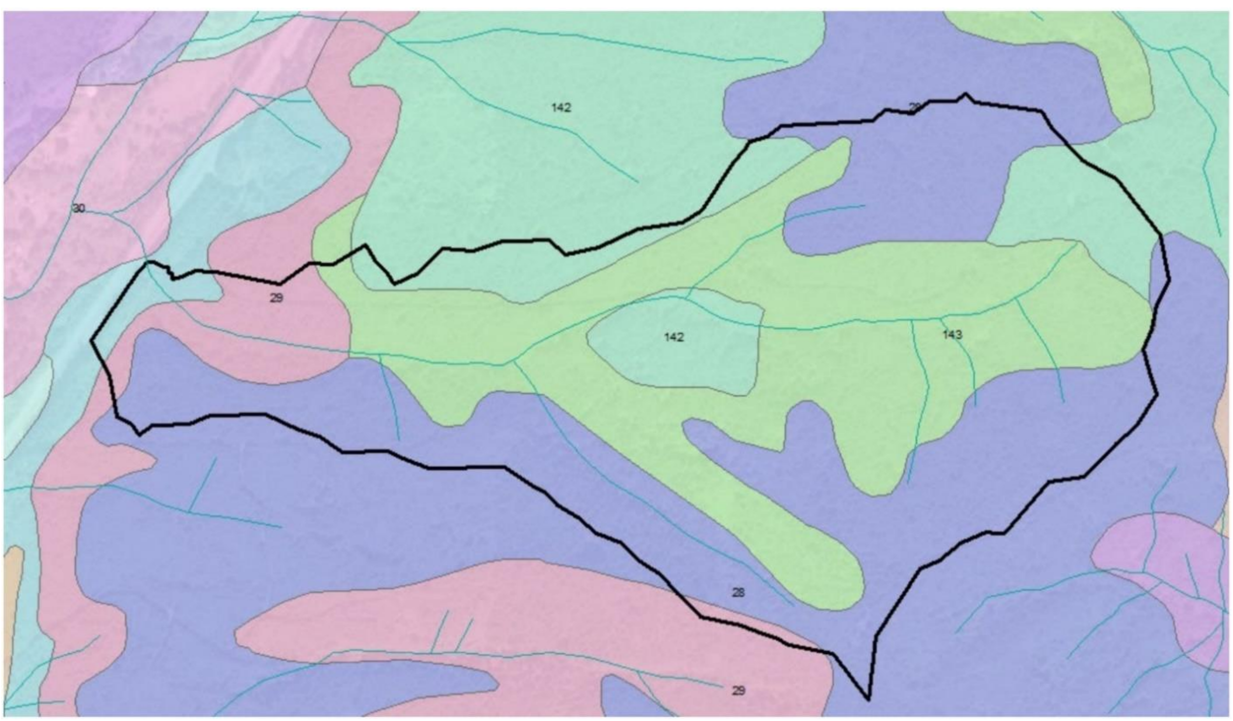


Figure 4: Soils Map

Table 1: Soils in the Watershed Draining to the Unnamed Stream

Map Unit Symbol (see Figure 4)	Soil Unit Name	Slope	Hydro Group
143	Tebo Silt Loam	30-65	B
142	Tebo Silt Loam	5-30	B
28	Centralia Silt Loam	8-30	B
29	Centralia Silt Loam	30-65	B
71	Lyre Very Gravelly Loamy Sand	0-8	B
30	Chehalis Silt Loam	0-3	B

2.4 Fish Presence in the Project Area

Table 2 provides a list of native fish potentially found in the Unnamed Tributary to Wildcat Creek. The stream may support coho salmon and steelhead, coastal cutthroat, and resident rainbow trout. In Washington State, coho salmon and steelhead are on the Priority Habitat and Species list defined by WDFW. Fish presence and use of the unnamed stream is uncertain. As stated in Section 2.1, salmonoids do not currently have access to the crossing due to a fish barrier downstream.

Table 2: Native fish species potentially present within the project area

Species	Presence (presumed, modeled, or documented)	Data source	ESA listing
Coho salmon (Oncorhynchus kisutch)	Presumed	Fish Passage Report (WDFW)	Not warranted
Steelhead (Oncorhynchus mykiss)	Presumed	Fish Passage Report (WDFW)	Not warranted
Coastal cutthroat trout (Oncorhynchus clarkii)	Presumed	Fish Passage Report (WDFW)	Not warranted
Resident rainbow trout (Oncorhynchus mykiss)	Presumed	Fish Passage Report (WDFW)	Not warranted

2.5 Wildlife Connectivity

The 1-mile-long segment that the unnamed Tributary to Wildcat Creek crossing falls in ranked a low priority for Ecological Stewardship and low priority for wildlife-related safety by WSDOT Headquarters (HQ) ESO. Adjacent segments to the west and east ranked high and medium priority. Despite being ranked as low priority, the tributary crossing is still identified as being within the range of the state-endangered fisher (*Pekania pennanti*). Part of the reason this section of highway is ranked low is because it is not adjacent to protected land such as a state or national park. However, large tracks of land both north and south of the highway are intact working forests owned by Green Diamond or Port Blakely. Ownership of these by forest management companies makes it likely that this land will remain working forests and thus suitable habitat for many native species for the foreseeable future. At the recommendation of the Wildlife Connectivity Memo, a 5-foot bench outside of the 2-year flood extends was added on the left-bank side of the channel for wildlife passage (WSDOT 2020).

2.6 Site Assessment

The site assessment is used to describe the context of the crossing location and to identify factors that should be addressed as part of the project.

2.6.1 Data Collection

The site assessment was performed over two site visits. The reach downstream of SR 8 was investigated on August 6, 2019, and the reach upstream was investigated on August 23, 2019. Both site visits included walking the creek and immediate areas around it while taking measurements pertinent to the geomorphic and habitat analyses. In addition, an existing stream topographic survey was performed by WSDOT in August 2019. Approximately 917 linear feet of stream was surveyed including about 300 feet upstream and 400 feet downstream of Culvert 993724.

The Unnamed Tributary to Wildcat Creek was previously surveyed by WDFW in 2002 and 2009. This survey determined that the channel upstream of Culvert 993724 is 18 percent pool and 82 percent riffle habitat over the 150 linear feet of stream surveyed. WDFW estimates 1.4 miles of potential habitat would be accessible upstream of Culvert 993724 if fish passage is restored at the SR 8 crossing.

An average bankfull width was determined from measurements taken at 6 locations. More detailed information about channel geometry is presented in Section 2.7.2. Pebble counts were conducted in three locations; this information can be found in Section 2.7.3.

2.6.2 Existing Conditions

The stream assessment began roughly 300 feet upstream of the SR 8 crossing. The upstream area of the watershed is heavily forested, and the unnamed stream channel contains a high volume of large woody material (LWM). The upstream watershed area has had minimal disturbance in recent years. Hillside vegetation is primarily large trees and ferns over uneven and steep terrain. The tributary watershed area has a strong v-shape and the morphology indicates a slowly eroding stream bed. The channel slope is steep in this upstream reach, over 5 percent in places and reaching to over 9 percent in the upper watershed. There is a single footbridge crossing the stream (Figure 5) roughly 240 feet upstream of SR 8. The path leading to the footbridge is overgrown and the bridge does not appear to interact with streamflow. The channel has a high degree of bed and bank complexity as well as abundant LWM. The channel is narrow, yet has complex flow paths within it, with some pool-riffle development. Banks are undercut in some places. Gravel is present through most of the upstream reach with higher levels of sand in the pools (Figure 6). Sand is also dominant in the substrate where large wood has forced pool formation.

Figure 5: Footbridge Crossing Unnamed Stream Upstream of Culvert 993724

Figure 6: Pool Upstream of Culvert 993724

Figure 7 shows the inlet to the existing culvert beneath SR 8. The inlet has a metal apron extending approximately 4 feet from the culvert opening. Culvert 993724 passes under SR 8 through a 204-foot-long corrugated metal pipe at a 3.4 percent slope. Figure 8 shows the culvert outlet. The culvert exits at the base of a steep, approximately 20-foot-deep ravine. The outlet area has a deposit of gravel and sand approximately 0.1-foot thick. The stream is in an open channel for approximately 50 feet downstream of the culvert and then passes through the Forest Culvert. The outlet of the Forest Culvert is perched approximately 3.9 feet above a downstream plunge pool. This drop renders the project reach and areas upstream of SR 8 inaccessible to salmonids (Figure 9) until this culvert is replaced or removed at some time in the future. The stream banks are incised on both sides of the plunge pool. Downstream of this pool, the bank height reduces as the channel bed is less incised and natural LWM becomes frequent within the channel. The channel has an approximately 2 percent gradient downstream of the Forest Culvert. The channel develops a sinuous pattern with pools at bends and riffles between the pools in this area. The channel narrows at the riffles and widens at the pools. LWM is common and frequently found at pools. Farther downstream, near residences, the stream transitions to a sand bed with dune-ripple features as it passes through a forested wetland and then confluences with Wildcat Creek roughly 400 feet downstream of SR 8.

Figure 7: Upstream Inlet of Culvert 993724

Figure 8; Downstream Outlet of Culvert 993724

Figure 9: Forest Culvert Outlet Plunge Pool

Groundwater was observed emerging from the ground just before the unnamed tributary reaches the confluence with Wildcat Creek. This water is coming from a leaky confined aquifer underlying the Wildcat Creek basin (Hart Crowser 1994). This aquifer is a source of drinking water for the City of McCleary and the surrounding rural areas. The water table is 10 to 20 feet below ground and can be considered to have connectivity to the surface flow in Wildcat Creek (Schanz and Zirkle 2007). Groundwater flows from northeast to southeast and the recharge zone for the aquifer is defined as northeast of McCleary (Hart Crowser 1994). Because the recharge zone is far from the project location, the culvert replacement project would have no impact on the aquifer.

2.6.3 Fish Habitat Character and Quality

The Unnamed Tributary to Wildcat Creek offers a mix of fair to good quality non-natal rearing habitat for salmonids. The existing, undersized Culvert 993724 beneath SR 8 is a 100 percent barrier to upstream fish migration. Aside from the culvert being a barrier, the immediate crossing area is in a forested habitat with dense canopy cover and perennial flow, providing some of the best fish habitat in the watershed.

The habitat upstream of Culvert 993724 is good quality. The reach has numerous pieces of LWM, significant riparian vegetation cover in a healthy forested habitat, and streambed substrate that consists predominantly of gravel and cobble but has localized areas of sand deposition. The upstream reach is on managed timber land with good canopy cover ranging from 50 percent to 90 percent. The channel upstream of Culvert 993724 is 18 percent pool and 82 percent riffle habitat over the 150 linear feet of stream surveyed. Aside from the complete fish passage barrier imposed by the perched Forest Culvert, the instream and riparian habitat quality downstream of Culvert 993724 is good. The average gradient throughout the lower reach is 3.3 percent and streambed substrate are generally in a natural condition (see Section 2.7.3). The forested habitat contains good riparian vegetation and canopy cover throughout but decreases in the downstream reaches as the channel borders residential properties.

The stream may support coho salmon and steelhead, coastal cutthroat, and resident rainbow trout. The stream would likely be used for non-natal rearing during the fall and winter prior to outmigration in the spring for coho salmon and for non-natal rearing and refuge during fall, winter and spring for steelhead, coastal cutthroat, and resident trout.

2.6.4 Riparian Conditions, Large Wood, and Other Habitat Features

There are several natural accumulations of large woody material (LWM) in the unnamed stream both upstream and downstream of Culvert 993724. The riparian area surrounding the stream provides good potential for LWM recruitment. Upstream of the culvert, several LWM pieces have formed logjams that create pools and cascading reaches. The downstream reach has fewer LWM pieces in the narrow channel, even though the banks are lined with coniferous and deciduous tree species.

2.7 Geomorphology

Geomorphic information provided for this site includes selection of a reference reach, discussion of the geometry and cross sections of the channel, and analysis of channel stability both vertically and laterally for the Unnamed Tributary to Wildcat Creek.

2.7.1 Reference Reach Selection

The most appropriate reference reach for this project is the reach downstream of the Forest Culvert but upstream of the transition to a forested wetland (Figure 10). This reference reach was chosen because it is a stable reach, beyond the influence of either Culvert 993724 or the Forest Culvert and receives all the water flowing through Culvert 993724. It is approximately 105 feet, or 13 channel widths, downstream of the Forest Culvert. The channel slope is between 2 and 3 percent. The channel bed in this location is a gravel and sand mixture with some bedform development. For bed surface conditions in this location, see Section 2.7.3. The bankfull width measurement for the reference reach is marked as bankfull width measurement 10 on Figure 11 and is provided in Table 3 in Section 2.7.2. Images of the reference reach were not included in the PHD.

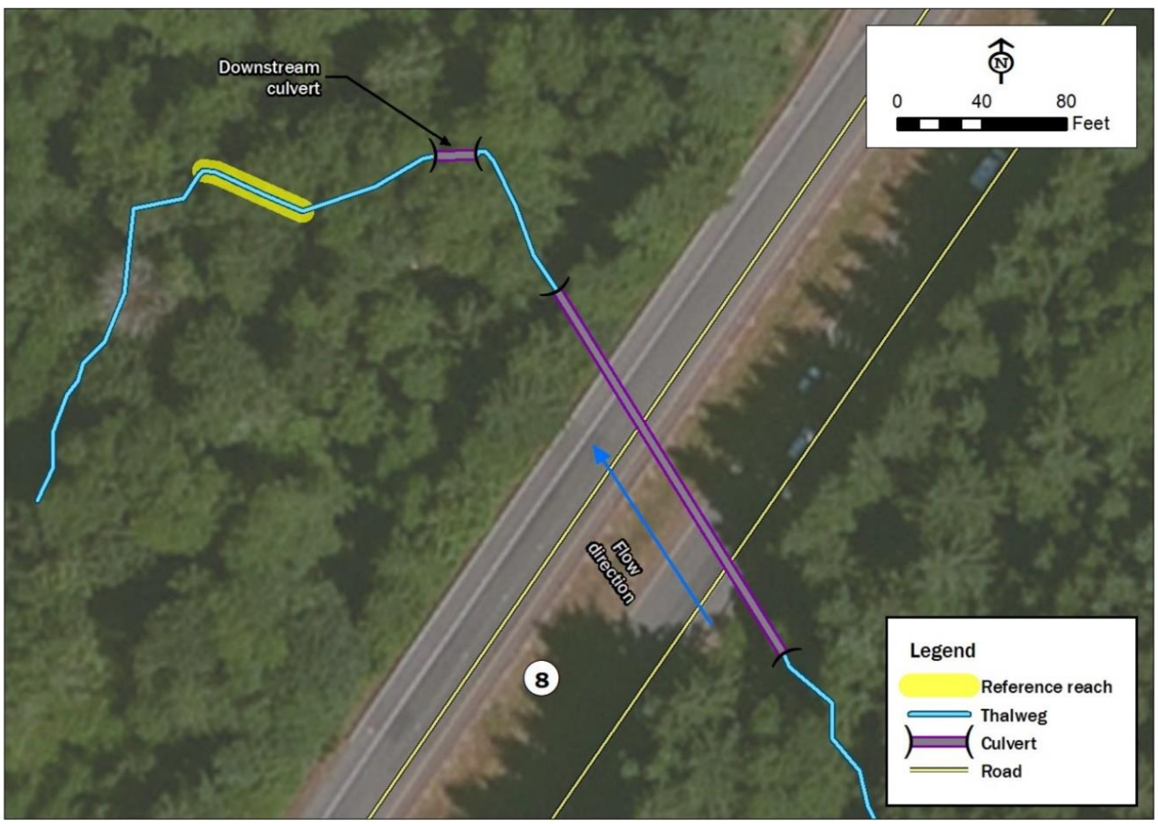


Figure 10: Reference Reach for Proposed Design of Culvert 993724

2.7.2 Channel Geometry

Bankfull widths were measured at three locations downstream of Culvert 993724 and three locations upstream of it (Figure 11). At each of these locations two measurements were made within 1 foot of each other and averaged together except at the downstream most location that only has a single measurement. The upstream bankfull widths measured as 9.0 feet, 9.0 feet, and 8.0 feet at the location closest to Culvert 993724. Downstream of the Forest Culvert, bankfull widths were measured at 7.9 feet and 7.8 feet, while the bankfull width measured between the Forest Culvert and Culvert 993724 was 9.1 feet (Table 3). The bankfull width determined for this design was 9.1 feet. Co-manager concurrence was not recorded in the original report.

Table 3: Bankfull width measurements

BFW #	Width (ft)	Incluced in design average?	Location Measured	Concurrence Notes
1 and 2	9.0	n/a	300 ft Upstream	n/a
3 and 4	9.0	n/a	180 ft Upstream	n/a
5 and 6	8.0	n/a	50 ft Upstream	n/a
7 and 8	9.1	n/a	20 ft Downstream (between culverts)	n/a
9 and 10	7.9	n/a	200 ft Downstream	n/a
11	7.8	n/a	400 ft Downstream	n/a
BFW used for design	9.1			
n/a – this information was not recorded in the original PHD.				

The channel geometry is consistent with that of a steep, stable, naturally incised channel on the upstream side of Culvert 993724. The rate of channel bed erosion appears to be conforming to the natural, geologic rate. The bank heights vary from 1.6 to 3.2 feet. The gradient decreases from 10 percent to 5 percent as the channel approaches the SR 8 crossing.

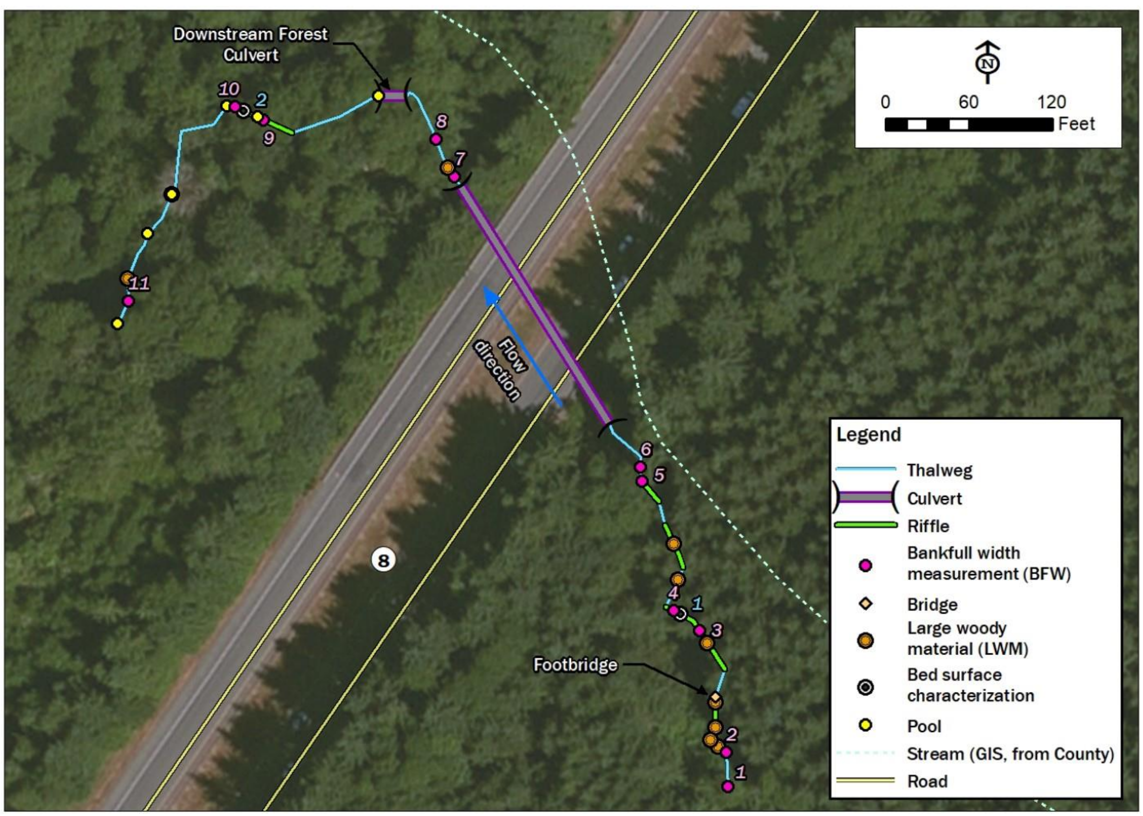


Figure 11: Locations for Channel Bed and Bankfull Width Measurements

Immediately downstream of Culvert 993724, bank heights are notably lower—less than 1 foot and remain low throughout the downstream channel length. The reduction in bank height reflects the overall decrease in channel slope to 1.25 percent on the downstream side of SR 8.

The outlet invert elevation of the Forest Culvert is 3.9 feet above the water surface in the downstream plunge pool (Figure 9). The banks on either side of the plunge pool are near vertical as outflow from the culvert has caused the channel to incise by 3.9 feet. The pool extends for 15 feet downstream of the culvert outlet. Downstream of the Forest Culvert the channel bed slope is 3.28 percent and the channel transitions to a more sinuous planform with riffle and pool bedforms. The bank heights are low, 0.7 to 0.8 foot, indicating a stable downstream channel geometry.

Further downstream vegetation changes from forested to a forested wetland. Slope, geometry, and channel bed sediments all change with the shift to wetland character. Gravels are no longer in transport and the channel bed is predominantly sands in this flat area near the confluence with Wildcat Creek. Channel sinuosity increases as the cohesive content increases. Banks are low but stable. Pools form at channel bends with sand riffles between bends (Figure 12).

Figure 12**: Channel Bed in the Unnamed Stream Approximately 300 Feet Downstream from Culvert 993724**

2.7.2.1 Floodplain Utilization Ratio

The 2013 WDFW WCDG present two methodologies for designing a bridge crossing—confined bridge design and unconfined bridge design. The method to be used is defined by the

Floodplain Utilization Ratio (FUR). The FUR is defined as the flood-prone width (FPW) divided by the bankfull width. The FPW is the water surface width at twice the bankfull depth, or the width at the peak of the 100-year flood. A ratio under 3.0 is considered a confined channel and above 3.0 is considered an unconfined channel.

The locations used for the FUR determination are shown in Figure 13. The results of the analysis are shown in Table 4. The flow is confined everywhere except just upstream of the crossing. The average FUR is 1.53, indicating that the channel is confined at the SR 8 crossing and the confined bridge design width criteria are the appropriate design criteria for this project.

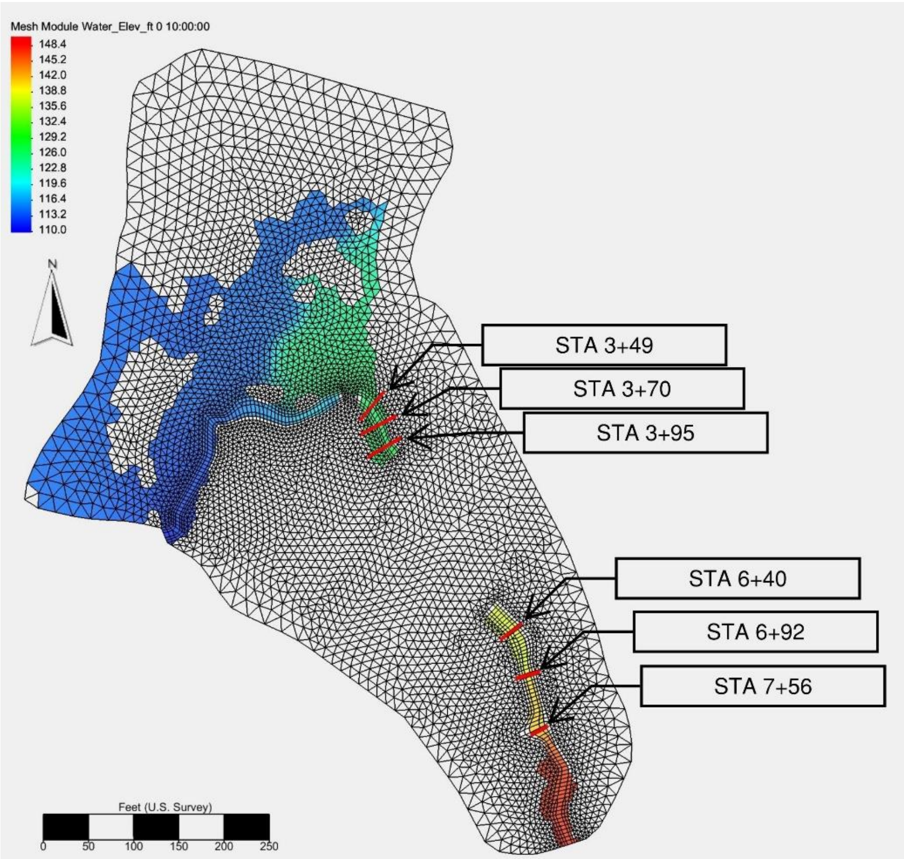


Figure 13: FUR locations

Table 4: FUR determination

Station	FPW (ft)	FUR	Confined/unconfined	Included in average FUR determination
3+49	24.91	1.24	Confined	Yes
3+70	27.27	1.36	Confined	Yes
3+95	23.63	1.32	Confined	Yes
6+40	21.67	3.23	Unconfined	Yes
6+92	5.79	1.00	Confined	Yes
7+56	5.39	1.00	Confined	Yes
Average	**18.11**	**1.53**	**Confined**	**Yes**

2.7.3 Sediment

The channel bed surface and structure were evaluated visually throughout the reach and in detail at three locations, shown in Figure 11. One location was upstream of Culvert 993724 and two locations were downstream of Culvert 993724. The stream maintains a gravel and sand bed throughout the upstream reach and for approximately 350 feet downstream of Culvert 993724. The first two bed characterization sites are within the gravel and sand channel bed reaches, and the gravel fraction was measured through a pebble count. At these sites, there is no evidence of an armored bed surface or structure in the arrangement of surface gravel. The amount of sand on the bed surface is relatively consistent with 18 percent in the upstream reach and 12 percent in the downstream reach. The third site is within the area with a sand bed. The channel bed was characterized at this location, but no gravels were measured.

The gravel fraction in the downstream sample is less than in the upstream sample (see Figure 14 and Figure 15). This reduction in surface coarseness fits within the context of a steep watershed and a channel that is reducing gradient with distance downstream. However, the presence of the Forest Culvert approximately 50 feet downstream of Culvert 993724 complicates the fining sediment pattern. The Forest Culvert invert is even with the channel bed on its upstream side but discharges into a plunge pool with a downstream invert that is approximately 3.9 feet above the pool water surface. The Forest Culvert creates a large discontinuity in the longitudinal profile of the stream (Figure 17).

Downstream of the Forest Culvert the channel bed is composed of gravel and sand with approximately 12 percent surface sand. Riffle-pool sequences form in this reach. It is within this reach that the second bed material surface structure was evaluated (see Figure 15). The sample site is approximately 155 feet downstream of Culvert 993724 and 105 feet downstream of the Forest Culvert. Further downstream the channel transitions to a sand bed with only patches of small pebbles and pea gravel on the bed surface. The third location where bed material was evaluated was in this reach approximately 355 feet downstream of Culvert 993724. Because of the fine nature of the channel bed at this location, the gravel distribution was not measured. Table 5 shows the gravel gradations for the two sites where pebble counts were taken. Downstream of this point the channel bed transitions to entirely sand.

Table 5: Sediment properties near the project crossing

Particle size	Upstream Pebble Count diameter (in)	Downstream Pebble Count diameter (in)	Average diameter for design (in)
Included in average?	Yes	Yes	-
$\mathbf{D_{16}}$	0.7	0.5	0.6
$\mathbf{D_{50}}$	1.1	0.9	1.0
$\mathbf{D_{84}}$	2.1	1.7	1.9
$\mathbf{D_{95}}$	3.7	3.4	3.5
$\mathbf{D_{100}}$	7.1	5.0	6.1

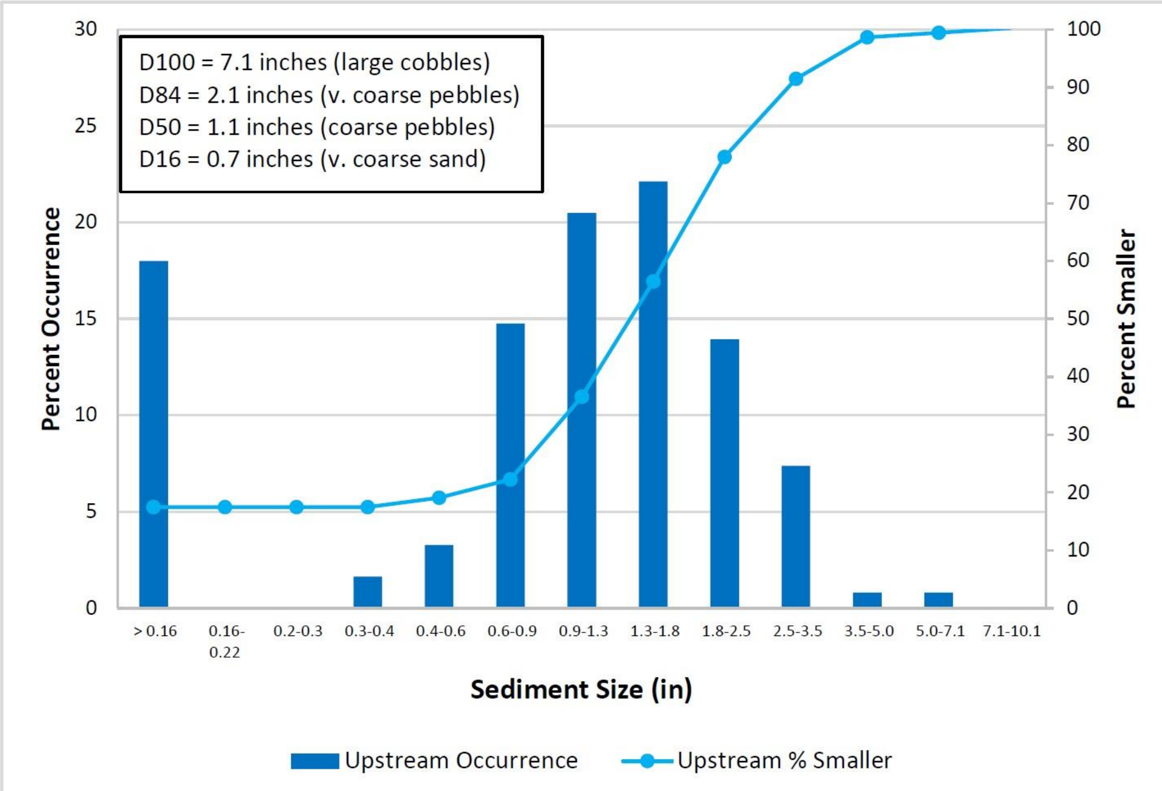


Figure 14**: Bed Surface Size Distribution at Location 1, Upstream of Culvert 993724**

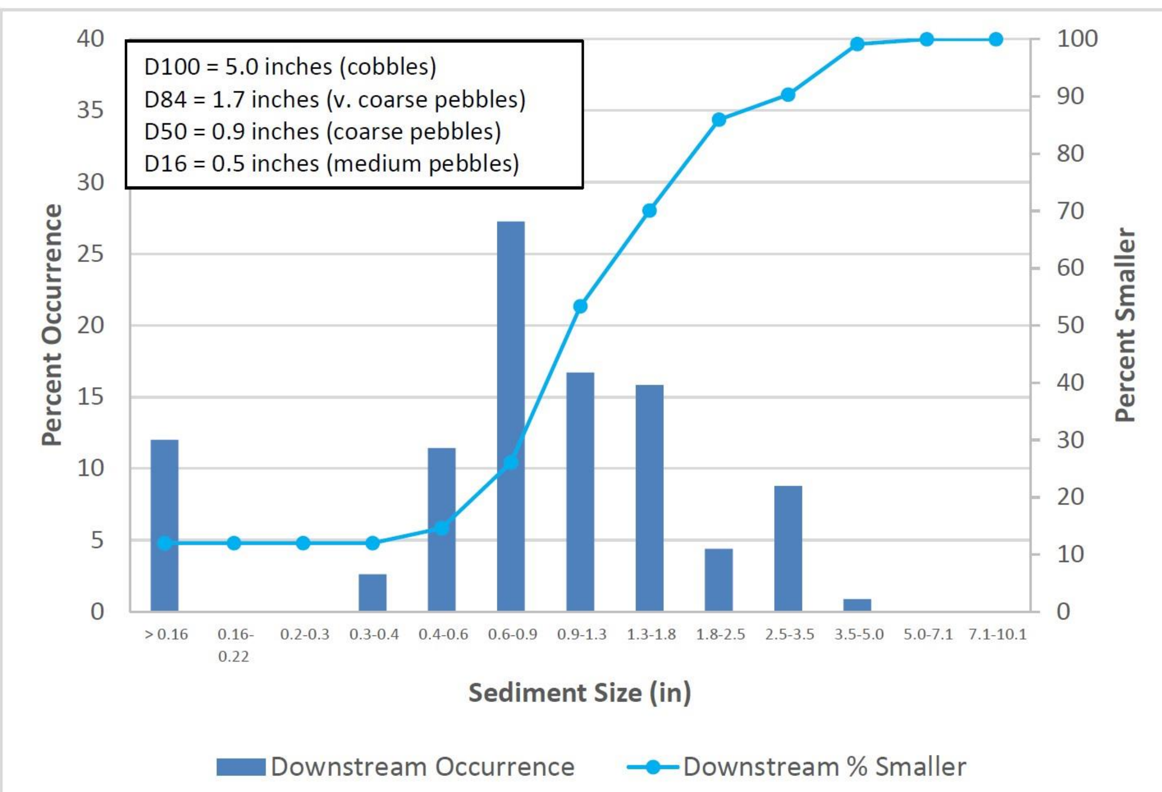


Figure 15: Bed Surface Size Distribution at Location 2, Downstream of Culvert 993724

Figure 16: Bed Surface Conditions at Location 2, Downstream of Culvert 993724

2.7.4 Vertical Channel Stability

Figure 17 shows a longitudinal profile through the project area. The Forest Culvert creates a grade control in the longitudinal profile of the stream. The Forest Culvert outlet is perched above the downstream bed, reducing the slope between the two culverts to 2.17 percent, creating backwater upstream of the Forest Culvert and a plunge pool downstream of it. The combination of backwatering and reduced slope has widened the channel, reducing the downstream transport of sediment from Culvert 993724 to the Forest Culvert. Approximately 0.1-foot of sediment has deposited in the downstream end of Culvert 993724. This deposit consists of gravels and sands over angular cobbles that resemble quarry spall.

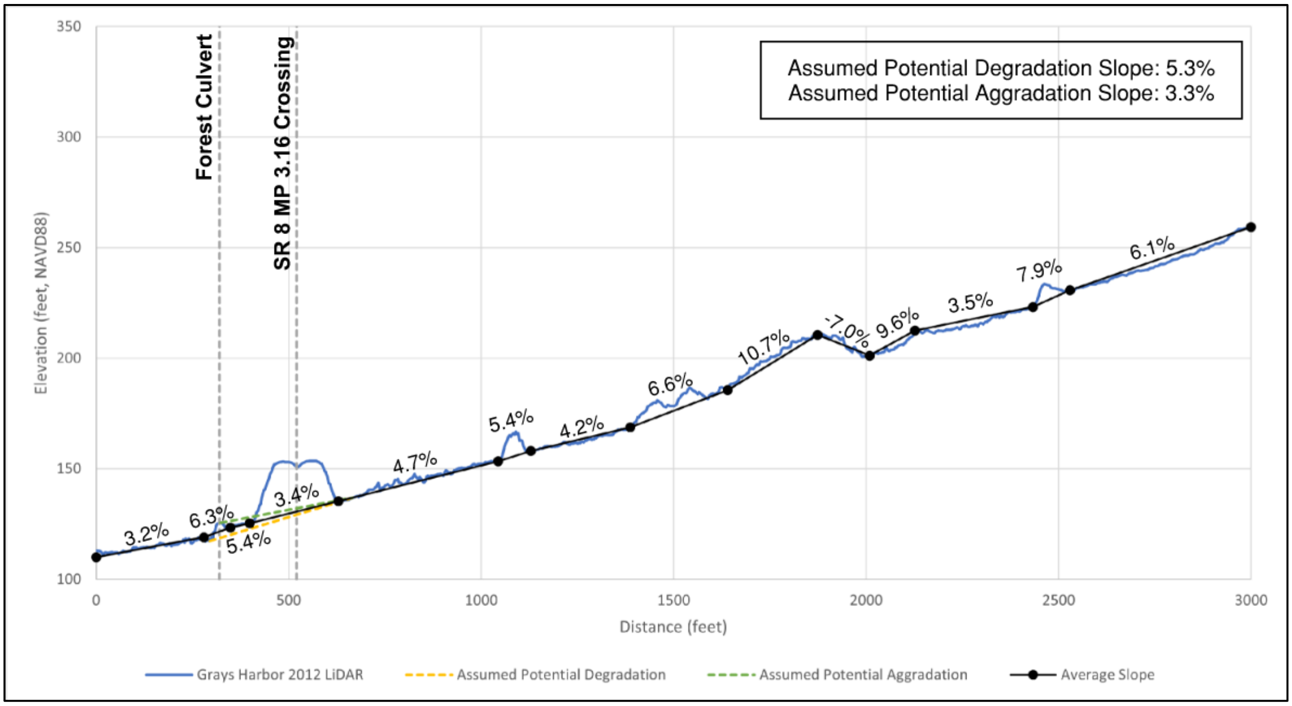


Figure 17: Thalweg Profile of the Unnamed Tributary to Wildcat Creek

Replacing Culvert 993724 is not expected to trigger a significant change in the channel bed profile through either erosion or deposition. The channel upstream of Culvert 993724 has a stable slope as far as available data shows. The proposed slope through the reconstructed reach is consistent with the upstream slope.

The channel bed downstream of Culvert 993724 is controlled by the presence of the Forest Culvert. As a result, the risk of major geomorphic changes in this stream is associated with the Forest Culvert. The Forest Culvert is creating a significant disconnect in the channel profile that will adjust when the Forest Culvert is either replaced or fails. If the Forest Culvert is replaced in a managed construction project, there will a natural regrade of the channel over time that will extend through the SR 8 crossing. If the Forest Culvert fails, there is the potential for a headcut to form and rapidly erode upstream through the new bridges beneath SR 8 where Culvert 993724 is currently located. The design has taken this future regrade into account. The proposed structure width and height is sufficient that any erosion resulting from potential failure of the Forest Culvert will not impair the functioning of the new structure beneath SR 8. See Section 4 for a detail discussion of the channel and structure design.

2.7.5 Channel Migration

The watershed area upstream of Culvert 993724 is characterized by steep hillsides and terraces. The watershed has a strong v-shape and the morphology indicates an actively incising system. The stream channel is narrow and has limited bedform development. Banks are undercut but low, indicating a stable system incising over geologic time scales. This channel is eroding vertically and not widening or migrating. There is negligible risk of channel migration upstream of SR 8 beyond what is natural.

As the unnamed tributary approaches the confluence with Wildcat Creek its channel is sinuous with a 1.25 percent gradient. The floodplain areas around the confluence of Wildcat Creek and the unnamed stream also have low topographic relief. There is the potential for future migration of the unnamed stream channel in this lower reach. There is also the potential for Wildcat Creek channel migration that could lengthen or shorten the tributary stream channel. As part of a culvert replacement study at MP 5.01, a site and reach assessment for Middle Fork Wildcat Creek was completed by WSDOT (Schanz and Zirkle 2007). The assessment found there has been migration of Wildcat Creek downstream of the confluence of the east and west forks since 1966. Much of this was attributed to adjustments following the construction of SR 8. However, there remains the potential for future channel migration in Wildcat Creek that could alter the unnamed stream alignment and/or longitudinal profile. The higher slope and coarser sediment in the reach within 200 feet of the downstream side of Culvert 993724 reduces the likelihood that any future channel migration in the lower reach of the unnamed stream or in Wildcat Creek will significantly impact the area within 200 feet of Culvert 993724.

3 Hydrology and Peak Flow Estimates

WSDOT 2019 guidelines offer multiple methods by which the flows in a drainage basin may be calculated. Three of these methods rely on the USGS regression equations specific to the location. We applied the stream delineation from Grays Harbor County and combined it with field reconnaissance findings to define drainage basin boundaries and drainage area that accounted for the steep upstream and low gradient downstream topographies.

The Flood Q regression tool was applied to determine flow rates at a range of mean recurrence intervals. The specific rainfall region was determined from the map of regression regions in Washington State. The annual precipitation value used in the computations was based on the 30-year annual precipitation data for years 1981–2010 as re-sampled on a 30-meter cell size from the PRISM Climate Group. Mean annual precipitation is 78.01 inches over a drainage area of 0.37 square mile. All of Grays Harbor County, including the project location, is in the USGS regression region 4.

WSDOT recognizes climate resilience as a component of the integrity of its structures and approaches the design of bridges and buried structures through a risk-based assessment beyond the design criteria. The largest risk to bridges and buried structures will come from increases in flow and/or sea level rise. The goal of fish passage projects is to maintain natural channel processes through the life of the structure and to maintain passability for all expected life stages and species in a system.

WSDOT evaluates crossings using the mean percent change in 100-year flood flows from the WDFW Future Projections for Climate-Adapted Culvert Design program. All sites consider the projected 2080 percent increase throughout the design of the structure. Appendix G contains the projected increase information for the project site. The design flow for the crossing is 75.1 cubic feet per second (cfs) at the 100-year storm event. The projected increase for the 2080 100-year flow is 55.3% percent, yielding a projected 2080 100-year flow of 116.6 cfs.

Table 6: Peak flows for the Unnamed Tributary to Wildcat Creek at SR 8

Mean recurrence interval (MRI) (years)	USGS regression equation (Region 4) (cfs)
2	23.0
10	44.7
25	56.1
50	65.2
100	75.1
500	96.7
Projected 2080 100	116.6

4 Water Crossing Design

This section describes the water crossing design developed for SR 8 MP 3.16 Unnamed Tributary to Wildcat Creek, including channel design, minimum hydraulic opening, and streambed design.

4.1 Channel Design

This section describes the channel design developed for the Unnamed Tributary to Wildcat Creek at SR 8 MP 3.16. This design does not propose variability in vertical, cross-sectional shape, and alignment. The stream will make its own variability after construction.

4.1.1 Channel Planform and Shape

The proposed typical cross-section (Figure 18) assumes the replication of downstream reference reach geometries. The general channel cross-sectional shape will include a channel bankfull width of 9.0 feet approximating the downstream reference reach BFW of 9.1 feet. The channel bottom will be 5 feet wide consisting of 10:1 slopes with the initial thalweg at the channel center. The thalweg will naturally adjust after construction based on hydraulic interaction with the boulder clusters and LWM placed within the bed (see Section 4.3.2) and sediment delivery from upstream. The channel banks will be constructed at 2:1 slopes from channel bottom up to the bankfull width. There are 10:1 floodplain benches on either side of the channel. The left-bank floodplain bench is 5 feet wide to accommodate wildlife. The right-bank floodplain bench is 2 feet wide. Beyond the floodplain benches grading is set at 2:1 slopes up to the bridge abutments or to tie-in to existing ground in open channel areas.

The proposed channel, shown in blue in Figure 19, has the same bankfull width and the general shape as the existing channel. This similarity will promote channel continuity as the proposed channel is expected to perform similarly to the upstream and downstream reaches.

Post construction, the channel is expected to self-adjust to the LWM and boulder clusters placed in the channel. Lateral migration is not expected, as discussed in Section 7.1. Degradation is expected at this crossing if the Forest Culvert fails or is replaced, as discussed in Section 7.2.

A low flow channel will be graded during construction to connect habitat features together and ensure the project does not create a low flow barrier. The low flow channel location will be directed by the engineer in the field during construction.

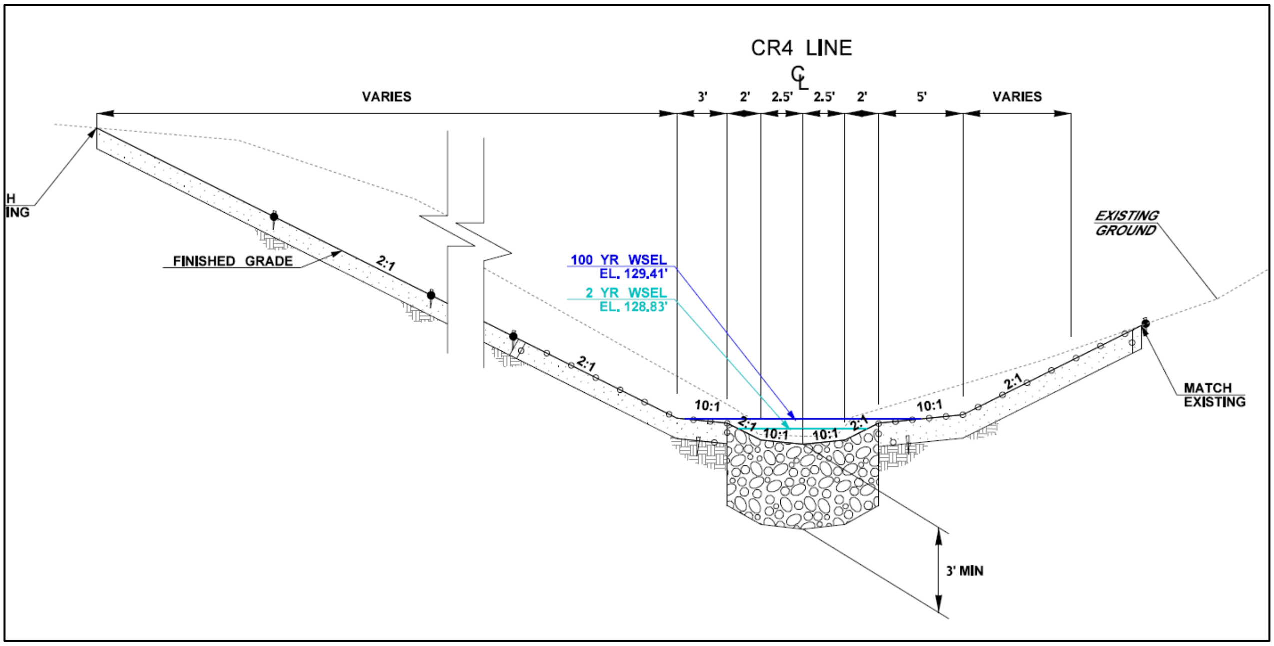


Figure 18: Design cross section

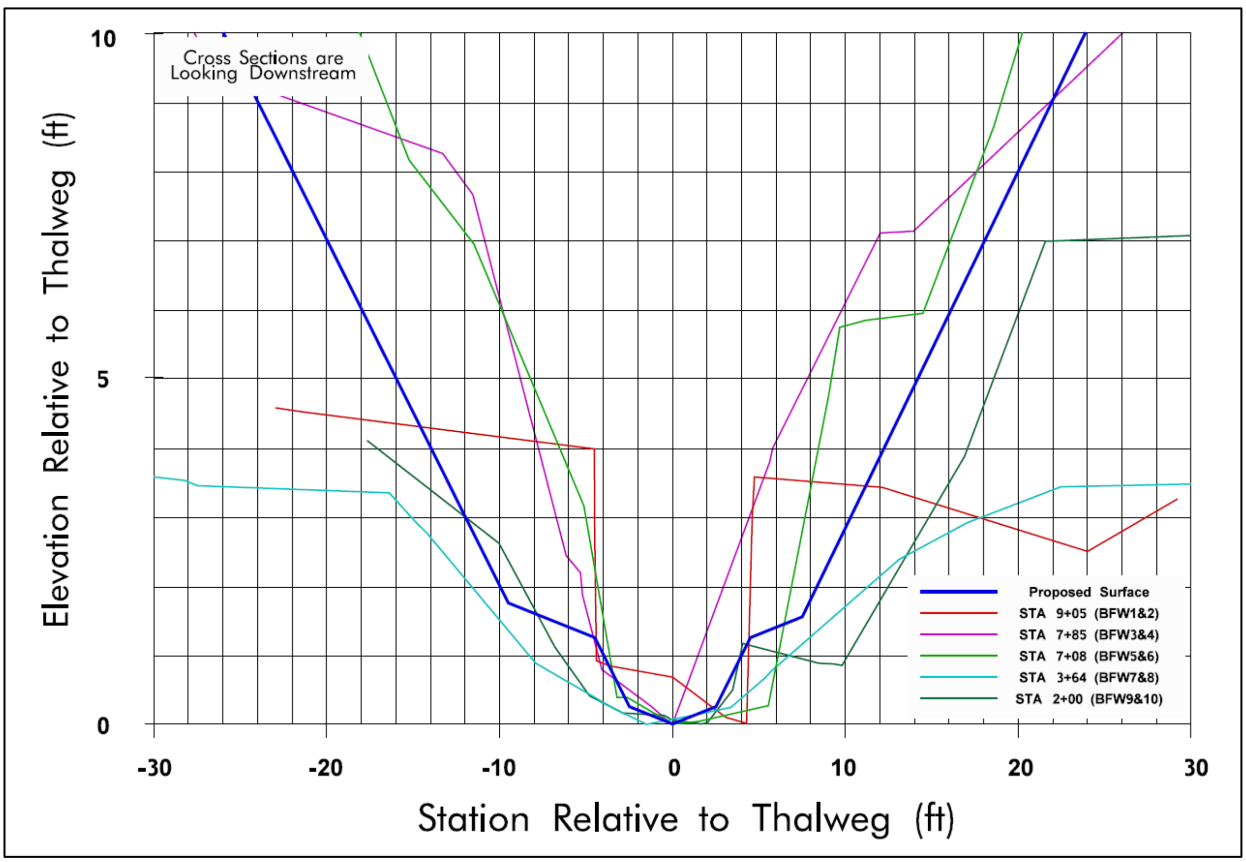


Figure 19: Proposed cross section superimposed with existing survey cross sections

4.1.2 Channel Alignment

It is proposed that the alignment of the stream be slightly skewed to SR 8 to maintain the existing alignment and to provide a smooth profile with the natural topography of the ravine. To match planform, a slight skew angle of 15 degrees was assumed. This alignment likely follows the historical, natural alignment of the stream. The vertical alignment will match the current average gradient in the adjacent reaches both upstream and downstream of the culvert.

4.1.3 Channel Gradient

The channel gradient is currently stable and at a consistent slope relative to the upstream reach. The design profile matches the average consistent gradient. The design slope through the new crossing is 4.02 percent and is similar to the current average gradient in the adjacent reaches both upstream and downstream of the crossing. This assumes the presence of the downstream Forest Culvert. The Forest Culvert is currently holding the channel gradient through the crossing and the channel gradient and geometry is relatively stable. Should the Forest Culvert fail or be removed, then the channel would adjust and drop by up to 6 feet at the location of the Forest Culvert and up to 3 feet at the location of SR 8. This potential degradation is discussed further in Section 7.2.

The design slope ratio is equal to 1.2. The SR 8 crossing is located on the apex of the historical alluvial fan of the unnamed stream so the undisturbed slope ratio should naturally be less than 1 given the concave nature of an alluvial fan profile. However, the Forest Culvert is currently altering this natural pattern.

4.2 Minimum Hydraulic Opening

The minimum hydraulic opening is defined horizontally by the hydraulic width and the total height is determined by vertical clearance and scour elevation. This section describes the minimum hydraulic width and vertical clearance; for discussion on the scour elevation see Section 7. See Figure 20 for an illustration of the minimum hydraulic opening, hydraulic width, freeboard.

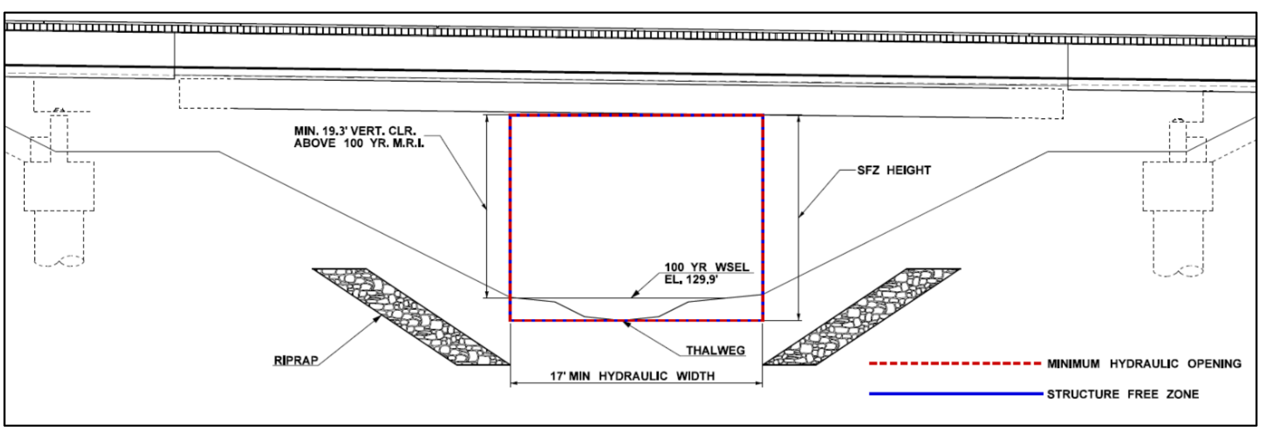


Figure 20: Minimum hydraulic opening illustration

4.2.1 Design Methodology

The proposed fish passage design was developed using the WCDG (Barnard et al. 2013) and the WSDOT *Hydraulics Manual* (WSDOT 2022a). Using the guidance in these two documents, the confined bridge design method was determined to be the most appropriate at this crossing because the Floodplain utilization ratio (FUR) is less than 3 (see Section 2.7.2.1).

4.2.2 Hydraulic Width

The starting point for the minimum hydraulic width determination of all WSDOT crossings is Equation 3.2 of the WCDG, rounded up to the nearest whole foot. For this crossing, a minimum hydraulic width of 13 feet was determined to be the minimum starting point.

Using equation 3.2 of the WCDG (span = 1.2 x bankfull width + 2 feet) the recommended span calculates as 1.2 x 9.1 + 2 = 12.9 feet. Assuming a minimum span of 13 feet results in a factor of safety of 1.43, which is likely a conservative estimate given the limited potential bankfull width variation over time. Therefore, 13 feet is reasonable to use for the confined bridge width in the design.

An alternative approach is to assume a factor of safety of 1.3. This calculates as 9.1 (BFW) x 1.3 = 11.8 feet then rounded up to 12 feet. The first method is the more conservative approach for this crossing and, therefore, was used as a starting point for this design.

After determining the BFW, the minimum hydraulic opening was increased to 17 feet to accommodate a 5-foot bench for wildlife crossing, as discussed in Section 2.5.

Lateral migration is a minimal risk at this site due low flow values and the small floodplain width around the crossing that has limited power to scour channel banks, as discussed in Section 7.1, so no additional width was added to account for channel migration.

Based on the factors described above, a minimum hydraulic width of 16 feet was determined to be necessary to allow for natural processes to occur under current flow conditions. The projected 2080 100-year flow event was evaluated for this width. Table 7 compares the velocities of the 100-year and projected 2080 100-year events.

Table 7: Velocity comparison for 17-foot structure

Location	100-year velocity (ft/s)	Projected 2080 100-year velocity (ft/s)
Reference reach (STA 2+12)	5.98	6.65
Upstream of structure (STA 6+92)	7.04	8.33
Through structure (STA 4+78)	8.42	9.55
Downstream of structure (STA 3+70)	2.74	3.42

No size increase was determined to be necessary to accommodate climate change. For detailed hydraulic results see Section 5.4.

4.2.3 Vertical Clearance

The vertical clearance under a structure is made up of two considerations: freeboard and maintenance clearance. Both are discussed below, and results are summarized in Table 8.

The minimum required freeboard at the project location, based on bankfull width, is 2 feet above the 100-year water surface elevation (WSE) (Barnard et al. 2013, WSDOT 2022a).

WSDOT is incorporating climate resilience in freeboard, where practicable, and has evaluated freeboard at both the 100-year WSE and the projected 2080 100-year WSE. The WSE is projected to increase by 0.3 feet for the 2080 projected 100-year flow rate. The minimum required freeboard at this site will be applied above the projected 2080 100-year WSE to accommodate climate resilience.

The second vertical clearance consideration is maintenance clearance. WSDOT HQ Hydraulics determines a required maintenance clearance if a height is required to maintain habitat elements, such as boulders or large woody material (LWM). If there are no habitat elements requiring maintenance clearance to maintain, the maintenance clearance is only a recommendation by WSDOT HQ Hydraulics, and the region determines the maintenance clearance required.

The channel complexity features in Section 4.3.2 include boulders within the structure. However, these will not need to be maintained as they are unlikely to move due to the tributary's low flow. Therefore, a maintenance clearance of 6 feet is recommended.

Table 8: Vertical clearance summary

Parameter	Downstream face of eastbound structure	Upstream face of eastbound structure	Downstream face of westbound structure	Upstream face of westbound structure
Station	4+62	5+05	5+39	5+82
Thalweg elevation (ft)	127.4	129.0	130.6	132.2
Highest streambed ground elevation within hydraulic width (ft)	129.1	130.8	132.3	133.9
100-year WSE (ft)	129.0	130.5	131.9	133.8
2080 100-year WSE (ft)	129.3	130.8	132.2	134.2
Required freeboard (ft)	2	2	2	2
Recommended maintenance clearance (ft)	6	6	6	6
Required minimum low chord, 100-year WSE + freeboard (ft)	131.0	132.5	133.9	135.8
Required minimum low chord, 2080 100-year WSE + freeboard (ft)	131.3	132.8	134.2	136.2
Recommended minimum low chord, highest streambed ground elevation within hydraulic width + maintenance clearance (ft)	135.1	136.8	138.3	139.9
Required minimum low chord (ft)	131.3	132.8	1334.2	136.2
Recommended minimum low chord (ft)	135.1	136.8	138.3	139.9
Design low chord (ft)	149.8	149.8	149.3	149.3

The proposed SR 8 eastbound and westbound bridge exceed both the required minimum freeboard and recommended minimum freeboard by as much as 10 feet.

4.2.3.1 Past Maintenance Records

WSDOT Olympic region maintenance records were unavailable at the time of writing of this report.

4.2.3.2 Wood and Sediment Supply

Tree transport is limited through the reach due to low velocity and low stream depth. The tributary is estimated to be able to transport a log that is 1-foot DBH and 10 feet long based on buoyancy calculations and stream alignment diameters. Upstream and downstream of the culvert has a lot of forested land cover, which will allow for plentiful wood recruitment opportunities. The sediment supply at the culvert location is composed of gravel and sand (see Section 2.7.3). Although the channel is currently stable, the removal or failure of the forest culvert could lead to potential headcutting and degradation. The degradation process would take a long time (see Section 7.2). The addition of LWM in the stream and boulders under the bridge will help retain sediment and slow degradation.

4.2.3.3 Impacts

This crossing meets freeboard requirements, so no substantial impacts are expected.

4.2.3.4 Impacts to Fish Life and Habitat

This crossing meets freeboard requirement so no substantial impacts to fish and habitat are expected.

4.2.4 Hydraulic Length

There is no length recommendation because a bridge structure is being proposed.

4.2.5 Future Corridor Plans

There are currently no long-term plans to improve SR 8 through this corridor.

4.2.6 Structure Type

Bridges are recommended by Headquarters Hydraulics and being designed for this crossing due to the length of the original culvert and the potential for future stream instability associated with the downstream Forest Culvert (ID 994773).

4.3 Streambed Design

This section describes the streambed design developed for the Unnamed Tributary to Wildcat Creek at SR 8 MP 3.16.

4.3.1 Bed Material

The recommended bed material gradation was obtained from the reference reach, downstream of the project site. The reference reach has a 2 to 3 percent slope. This is less than the slope of the proposed crossing and existing channel reach upstream of Culvert 993724. However, the upstream reach is in a different geologic setting and Culvert 993724 is near the apex of a historical alluvial fan. The alluvium in the reference reach downstream of Culvert 993724 and the Forest Culvert is a better representation of the type of bed material size sorting that can be expected. The largest bed material sizes measured in the reference reach are finer than what would be naturally deposited on an alluvial fan apex. For that reason, boulder clusters have been implemented into the design. The lack of any surface armoring in the bed upstream and downstream of SR 8 indicates that when there is a large flow, the full bed surface is likely mobilized. The proposed mixture is met by using 50 percent Streambed Sediment and 50 percent 6-inch streambed cobbles per Section 9-03.11(1) and Section 9-03.11(2) of the WSDOT Standard Specifications. This material mixture provides a good place for fish spawning. Since the Forest Culvert is a 100 percent fish barrier, residential fish will benefit initially until the Forest Culvert is fixed or fails.

The proposed D_{50} and D_{84} are mobile during the 2-, 100-, 2080 projected 100-, and 500-year flood events. For detailed bed material calculations see Appendix C.

Table 9: Comparison of observed and proposed streambed material

Sediment size	Observed diameter for design (in)	Proposed diameter (in)
$\mathbf{D_{16}}$	0.6	0.25
$\mathbf{D_{50}}$	1.0	1.3
$\mathbf{D_{84}}$	1.9	3.8
$\mathbf{D_{95}}$	3.5	5.5
$\mathbf{D_{100}}$	6.1	6.0

4.3.2 Channel Complexity

This section describes the channel complexity of the streambed design developed for the Unnamed Tributary to Wildcat Creek at SR 8 MP 3.16.

4.3.2.1 Design Concept

Channel complexity can help form and maintain the appropriate channel planform and shape. Boulder clusters will be placed under the bridge embedded into the streambed material, as seen in Figure 21. This will help create a cascade type of bedform below the bridge structure that can easily adjust over time if the downstream culvert is removed.

The proposed design for the LWM is shown in Figure 21 and detailed in the design drawings included in Appendix D. LWM will be installed within the restored reaches upstream and downstream of the Unnamed Tributary to Wildcat Creek according to the Hydraulics Manual and Fox and Bolton (2007). LWM will not be placed under the bridges.

According to “A Regional and Geomorphic Reference for Quantities and Volumes of Instream Wood in Unmanaged Forested Basins of Washington State” (Fox and Bolton 2007), with a BFW of 9.1 feet, the minimum volume of the LWM key pieces is calculated to be 1.31 cubic yards. A log with rootwad that is 18 inches in diameter and 25 feet long, satisfies the criteria for a key piece. The 75th percentile of key piece density is 3.3 key pieces per 100 feet. With 278 feet of regrading proposed at this site, the LWM targets are 9 key pieces, 32 total pieces, and volume of 109.8 cubic yards.

To satisfy the volume target, the proposed design incorporates buried logs. By burying some pieces, logs can be stacked vertically. This allows a larger volume of wood to fit within the regraded channel and still have most logs engaged within the channel's low flow area. Buried logs will take longer to decompose than surface logs so they will remain in the system longer. The buried logs will also become exposed when the Forest Culvert is removed and degradation occurs. No buried logs will interact with the buried revetment discussed in Section 8.

The proposed design, shown in Figure 21and Appendix D, incorporates 28 key pieces and 44 total pieces of LWM, which exceed the targets. A volume of 110.0 cubic yards of LWM is proposed, which exceeds the recommended volume. To ensure the constructability of the LWM design, three types of log clusters are proposed, as seen in Appendix D. The different clusters provide variability in habitat enhancement and aesthetics while providing clear plans for the contractor.

LWM placement will have no direct benefits to anadromous salmonids, only resident trout, until the downstream Forest Culvert fish barrier is removed. Due to the small size of the stream and its location, this site is not used for recreational swimming or boating. LWM would be low risk to any recreational users on foot.

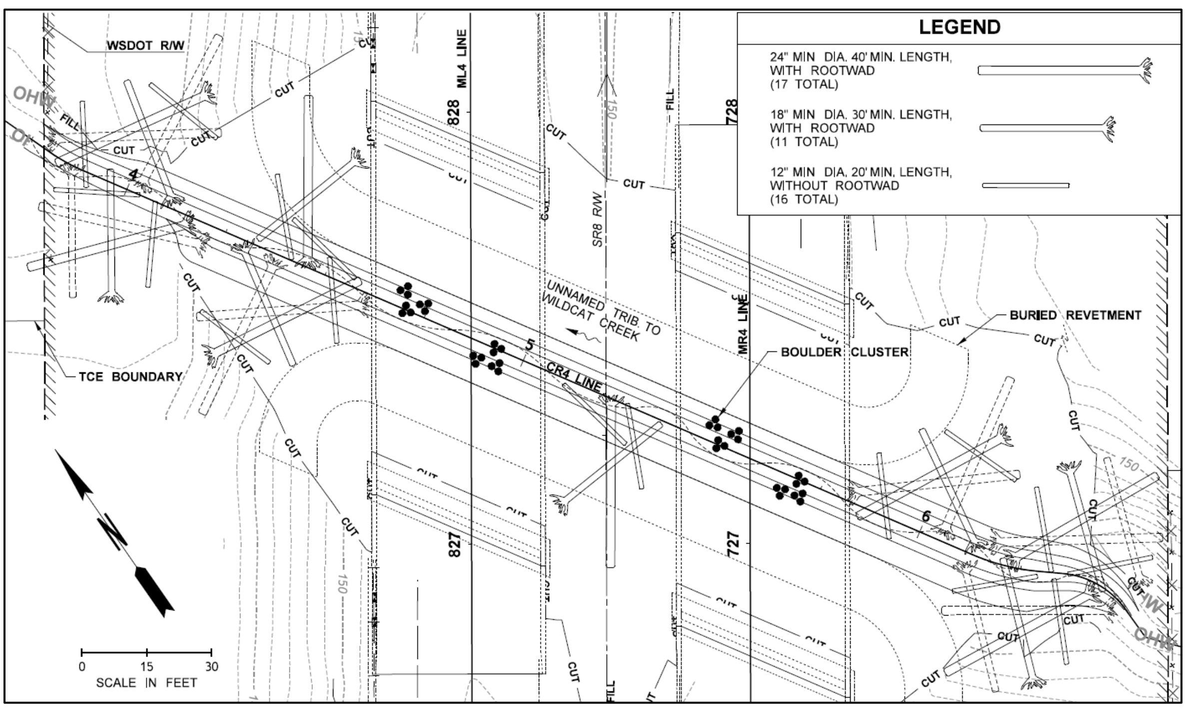


Figure 21: Conceptual layout of habitat complexity

4.3.2.2 Stability Analysis

For simple multi-log structures, large woody material stability analysis is typically completed using the USFS-supplied *Computational Design Tool for Evaluating the Stability of Large Wood Structures* Excel program (Rafferty 2016). The interactions between logs are normally entered into the spreadsheet to determine the stability of each individual log in a structure.

This approach was used for Cluster D. However, it was not possible for Clusters A or B due to the complexity of the log interactions in the clusters. Therefore, for these clusters, the individual stability of each log was assessed based on weight and buoyancy only. As long as each log is stable from its own weight, then interaction forces were not included. In Clusters A and B, only the small 12-inch diameter, 20-foot length logs needed to include interaction forces to verify stability. So, the interaction between these small logs and the log pinning them down were entered into the calculation spreadsheet. See Appendix F for the implementation of this approach.

The stability analysis was completed using the hydraulic modeling results from the 100-year flood. All calculations are included in Appendix F, and a summary of the stability of individual logs in a cluster is shown in Table 10. The USFS-supplied tool's assumptions include:

- Flows are not highly turbulent
- Stable and uniform stream geometry
- No debris flows
- Relatively low energy stream that transports sediment smaller than cobbles
- Simple log geometry (e.g., no branches, no partial rootwads)

Because the flow in the unnamed tributary is so low, even during a 100-year event, the calculation spreadsheet was unable to calculate the horizontal forces for some logs. This occurs when the cross-sectional area of the log is greater than the wetted area of the stream, which leads to an imaginary result in one of the program's internal calculations. The design team has made the assumption that if the cross-sectional area of the logs is greater than the wetted area, then the water will not have sufficient force to move a log of that size. The pieces of LWM that experience this problem have the horizontal force balance marked with an "N/A" in Table 10. The LWM placed in this channel will be self-ballasting and will not require anchoring or lashing.

Table 10: Summary of log ballast requirements

Cluster Type	Log (ID number)	Diameter (in)	Length (ft)	Vertical Force Balance (lbf)	Horizontal Force Balance (lbf)	Anchor requirements	
						Required ballast	Number of rock collars (three-man)
A	1	18	30	-950	-119	N/A	N/A
	2	24	40	-4,031	-2,960	N/A	N/A
	3	24	40	-24,122	N/A	N/A	N/A
	4	24	40	-35,963	N/A	N/A	N/A
	5	12	20	-2,301	-1,994	N/A	N/A
	6	12	20	-1,975	-1,335	N/A	N/A
B	1	18	30	-1,585	-1,009	N/A	N/A
	2	24	40	-4,113	N/A	N/A	N/A
	3	18	30	-3,175	-8,358	N/A	N/A
	4	24	40	-16,278	-60,427	N/A	N/A
	5	12	20	-845	-594	N/A	N/A
	6	12	20	-3,932	-3,091	N/A	N/A
D	1	24	40	-4,318	N/A	N/A	N/A
	2	18	30	-4,031	N/A	N/A	N/A
	3	12	20	-2,293	-1,679	N/A	N/A
	4	12	20	-2,336	-1,927	N/A	N/A

a. Assumes boulders with submerged specific gravity of 1.65.
b. Negative value indicates anchor and overburden moments exceed buoyant moments.

5 Hydraulic Analysis

The hydraulic analysis of the existing and proposed SR 8 Unnamed Tributary to Wildcat Creek crossing was performed using the United States Bureau of Reclamation's (USBR's) SRH-2D Version 3.2 computer program, a two-dimensional (2D) hydraulic and sediment transport numerical model (USBR 2017). Pre- and post-processing for this model was completed using SMS Version 13.1.14 (Aquaveo 2021).

Two scenarios were analyzed for determining stream characteristics for the Unnamed Tributary to Wildcat Creek with the SRH-2D models: (1) existing conditions with the 4-foot-diameter culvert under SR 8 and (2) proposed conditions with the proposed SR 8 bridges installed, accommodating the 17-foot-wide minimum hydraulic opening width.

5.1 Model Development

This section describes the development of the model used for the hydraulic analysis and design.

5.1.1 Topographic and Bathymetric Data

The channel geometry data for the existing conditions model were obtained from the MicroStation and InRoads files supplied by the WSDOT Project Engineer's Office (PEO), which were developed from topographic surveys performed by WSDOT in August 2019. The survey data were supplemented with 2012 Grays Harbor light detection and ranging (LiDAR) data obtained from Grays Harbor County. Proposed channel geometry was developed from the proposed grading surface created by David Evans and Associates, Inc. during design. All survey and LiDAR information is referenced against the NAVD 88 vertical datum.

5.1.2 Model Extent and Computational Mesh

The existing and proposed conditions models extended approximately 285 feet upstream of the upstream inlet of Culvert 993724 and 295 feet downstream of the outlet of Culvert 993724, to the confluence with Wildcat Creek. The existing conditions model includes two culverts: the SR 8 culvert (993724) and the Forest Culvert.

The existing conditions mesh, shown in Figure 22, has 5185 nodes and 9476 elements. Paving (triangular) mesh type is used everywhere but the unnamed tributary's channel, where the mesh type is patch (quadrilateral). The proposed conditions mesh, shown in Figure 23, has 5714 nodes and 10246 elements. Like the existing conditions model, patch mesh type is used in the channel, and paving mesh type is used everywhere else.

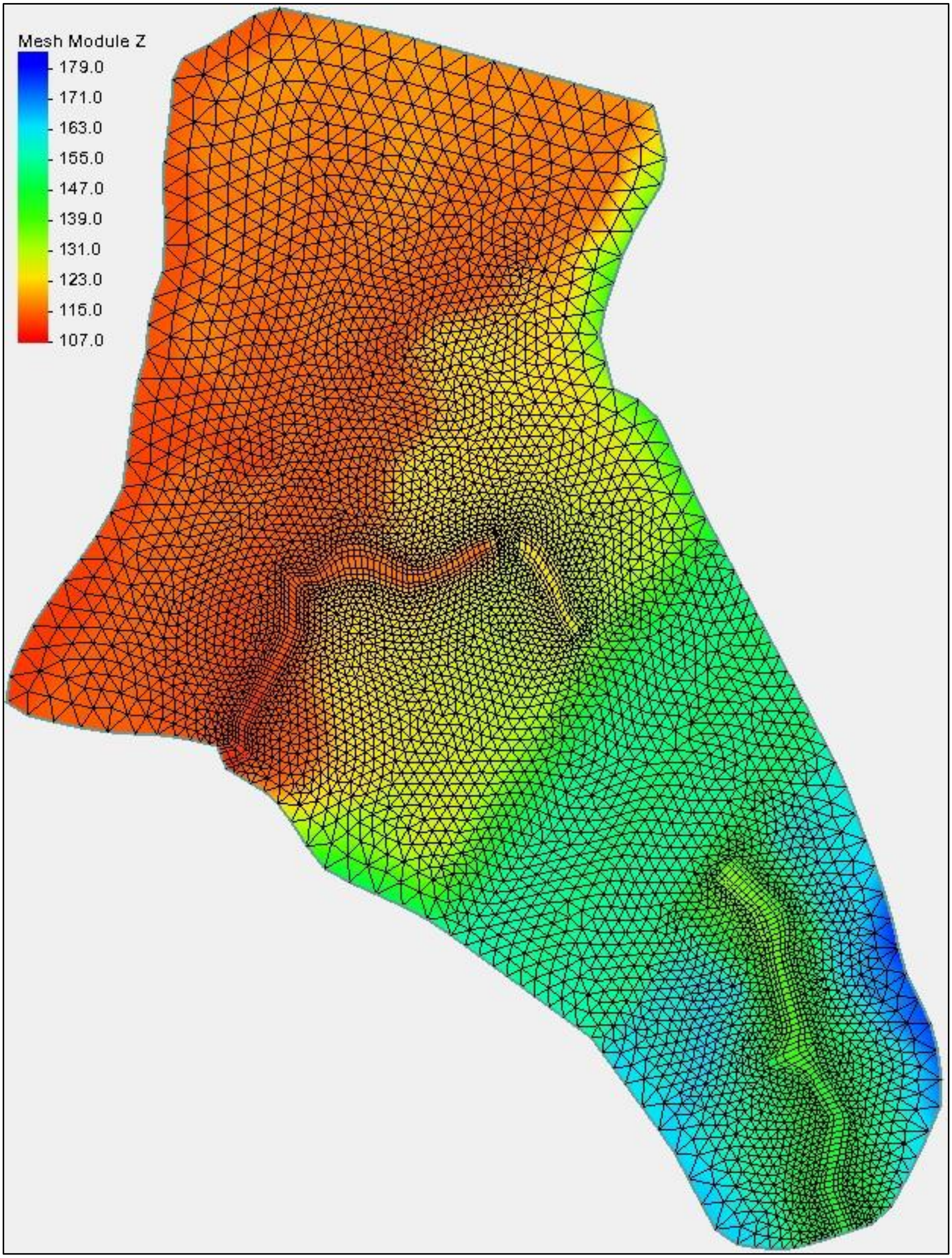


Figure 22: Existing-conditions computational mesh with underlying terrain

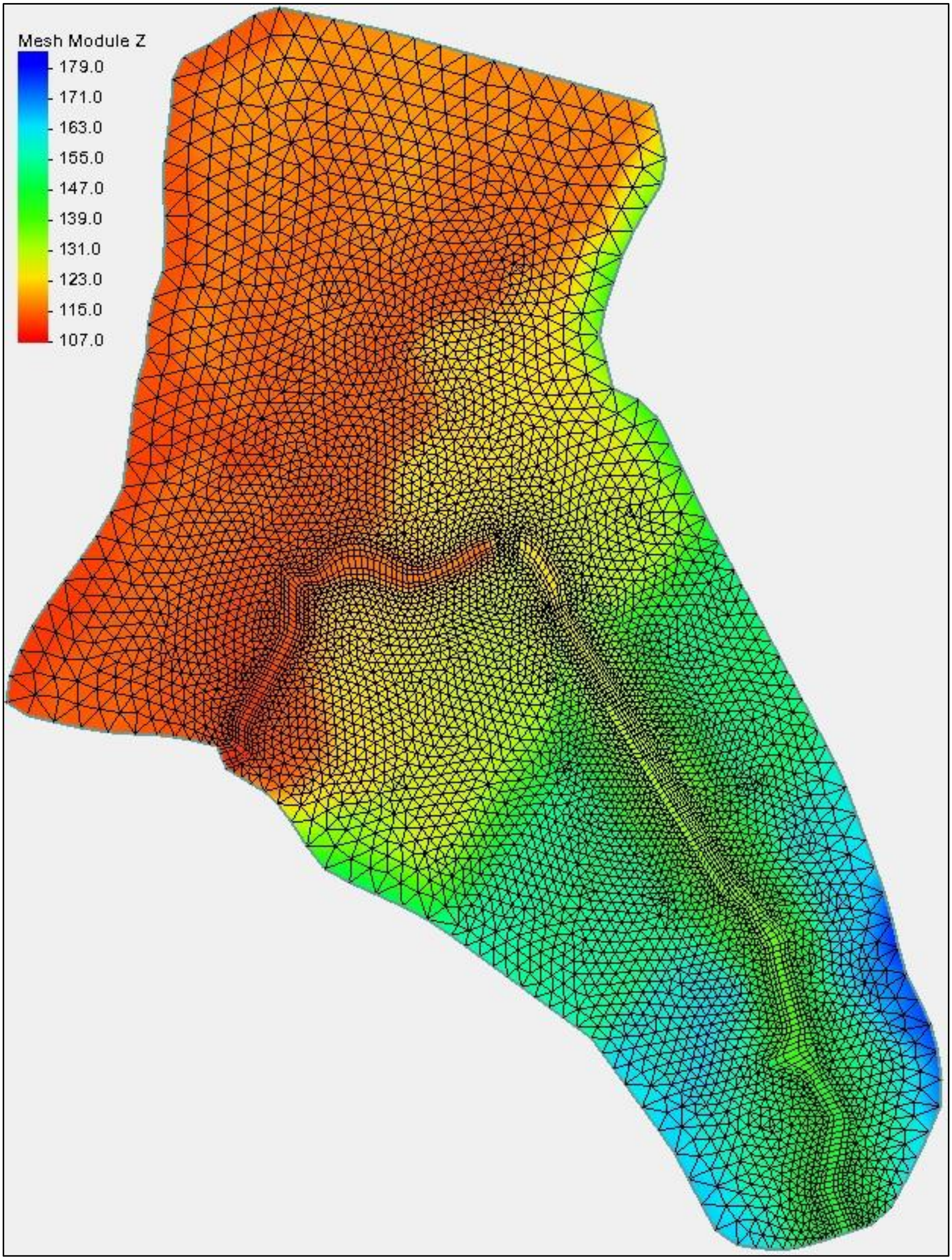


Figure 23: Proposed-conditions computational mesh with underlying terrain

5.1.3 Materials/Roughness

The Manning's "n" values used in the existing conditions model, shown below in Table 11, are based on the WSDOT Hydraulics Manual (WSDOT 2019a) and professional judgement to represent the creek channel, roads, fields, and vegetated floodplain.

Roughness values used in the existing and proposed conditions models are mostly the same with a few exceptions. The existing conditions materials are shown in Figure 24. The proposed conditions materials (Figure 25), incorporate the LWM that will be placed in the channel, the grass that is expected to grow along the channel benches under the proposed bridges, and the proposed channel. The LWM is modeled by utilizing a general roughness because to the large number of logs that will be placed in the channel make it impractical to model them as channel features. The proposed channel roughness is slightly larger than the existing channel to model the proposed boulder clusters.

Table 11: Manning's n hydraulic roughness coefficient values used in the SRH-2D model

Material	Manning's n
Existing Stream Channel	0.035
Paved Road	0.012
Forest	0.08
Forested Wetland	0.06
Plunge Pool	0.05
LWM	0.08
Grass	0.035
Proposed Stream Channel	0.04

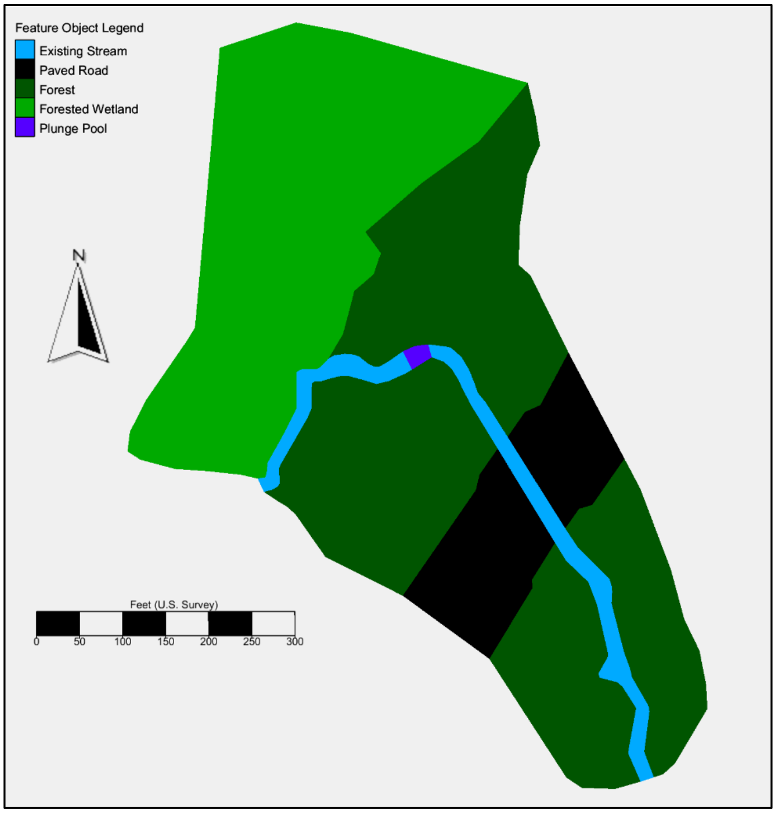


Figure 24: Spatial distribution of existing-conditions roughness values in SRH-2D model

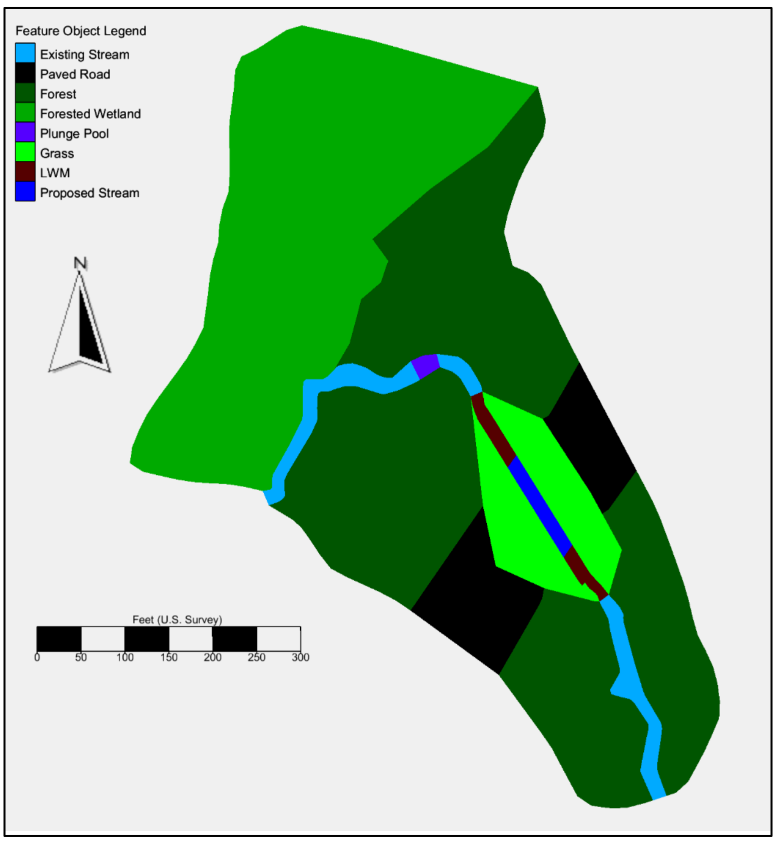


Figure 25: Spatial distribution of proposed-conditions roughness values in SRH-2D model

5.1.4 Boundary Conditions

The locations of the boundary conditions used in the existing and proposed conditions models are shown in Figure 26 and Figure 27, respectively. The inlet boundary conditions for both modeling conditions are the same and were assumed to be steady state flow. Flow values used in the modeling are shown in Table 6.

The existing Culvert 993724 was modeled as a 4-foot diameter corrugated steel pipe using the one-dimensional HY-8 model (FHWA Version 7.60) coupled to the SRH-2D model. The HY-8 parameters for this culvert are shown in Figure 28. The Forest Culvert was modeled as a 3-foot diameter corrugated steel pipe in HY-8. The HY-8 parameters for the Forest Culvert are shown in Figure 29.

The downstream boundary conditions were assumed to be the normal depth given a slope of 3.28% and a composite Manning's n of 0.04. The flow used to determine the normal depth was the inlet flow, which is described in Table 6 for each flow event. The normal depth rating curve across the flows described in Table 6 is shown in Figure 30.

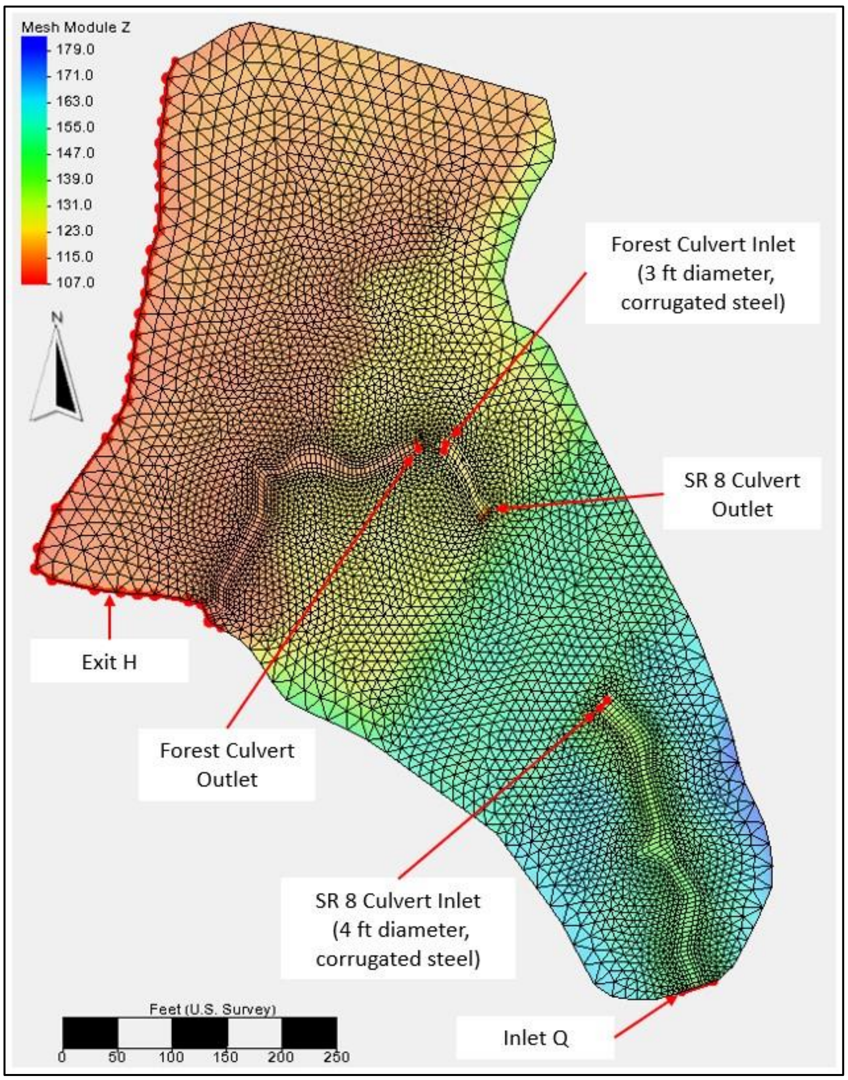


Figure 26: Existing-conditions boundary conditions

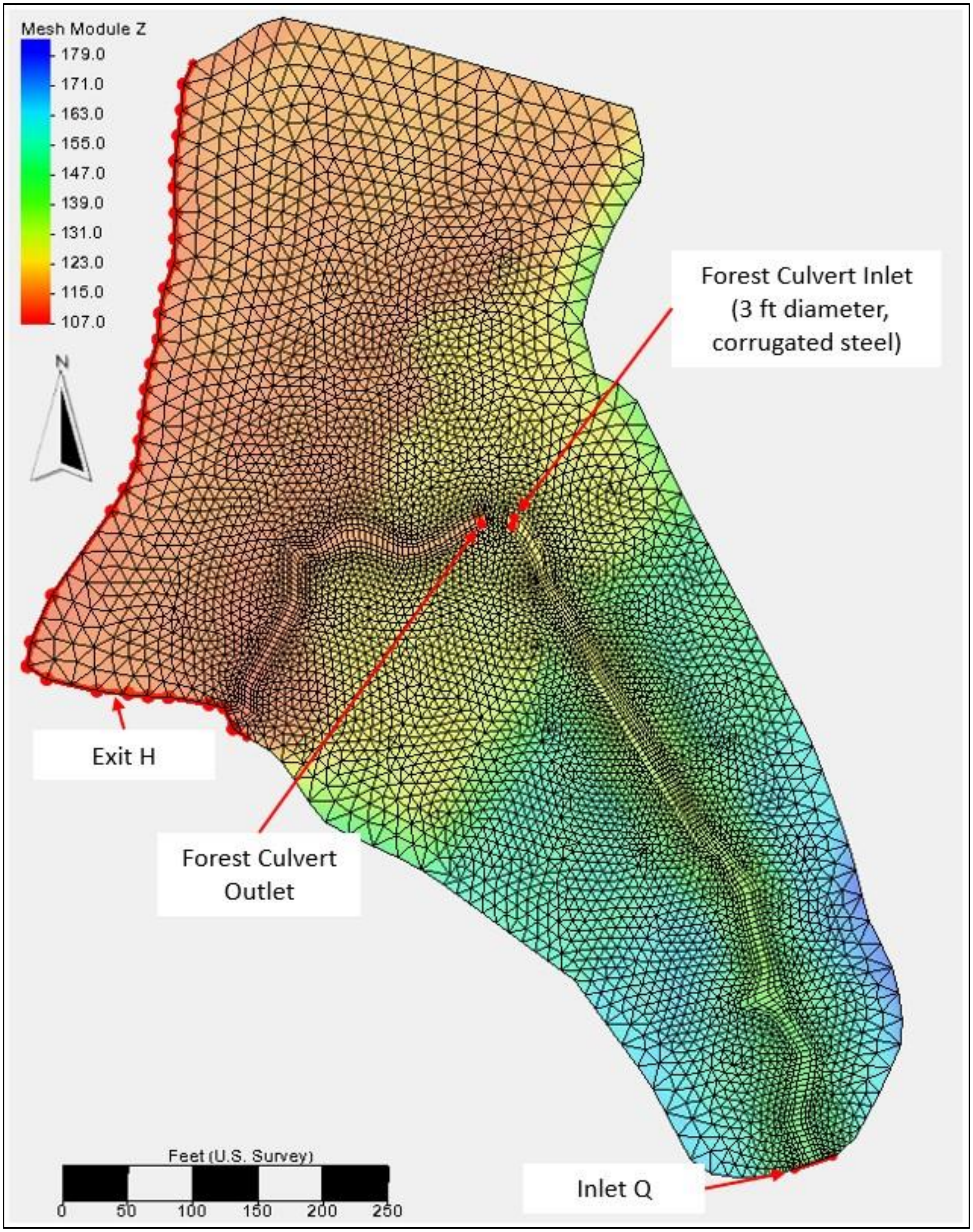


Figure 27: Proposed-conditions boundary conditions

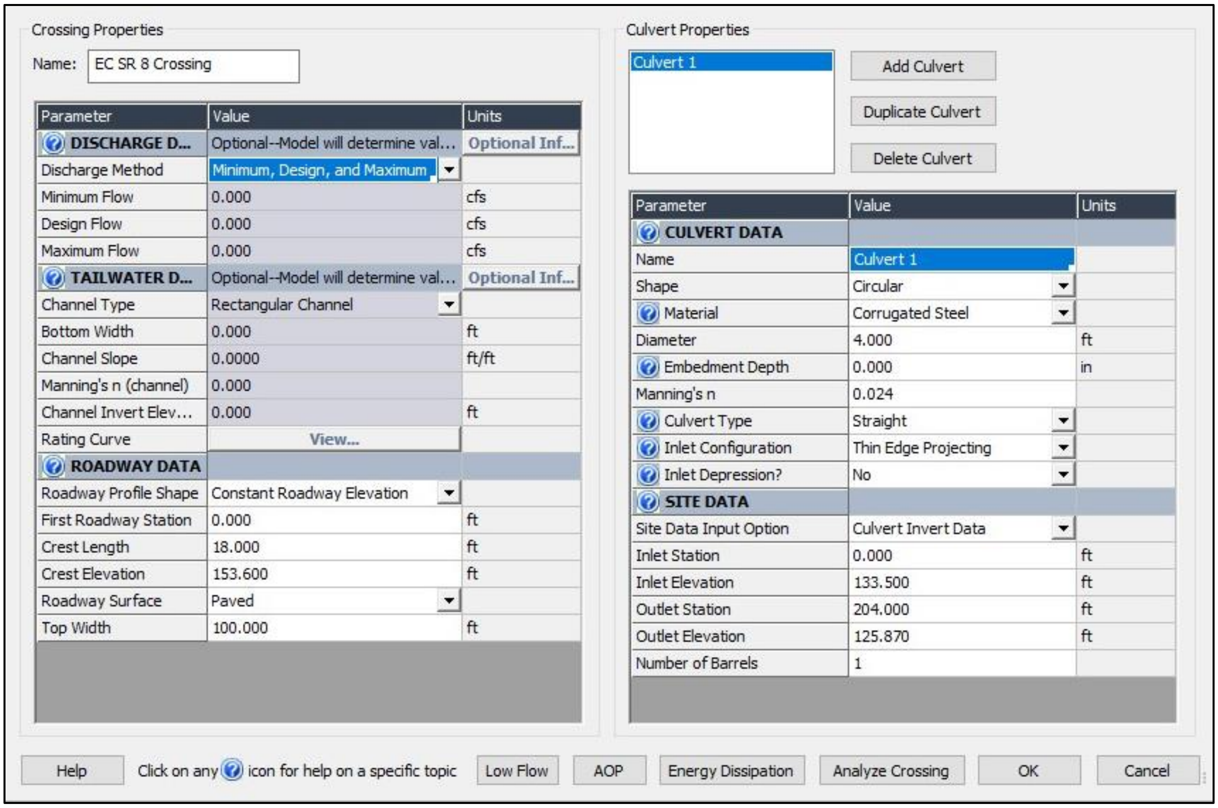


Figure 28: Culvert 993724 HY-8 culvert parameters

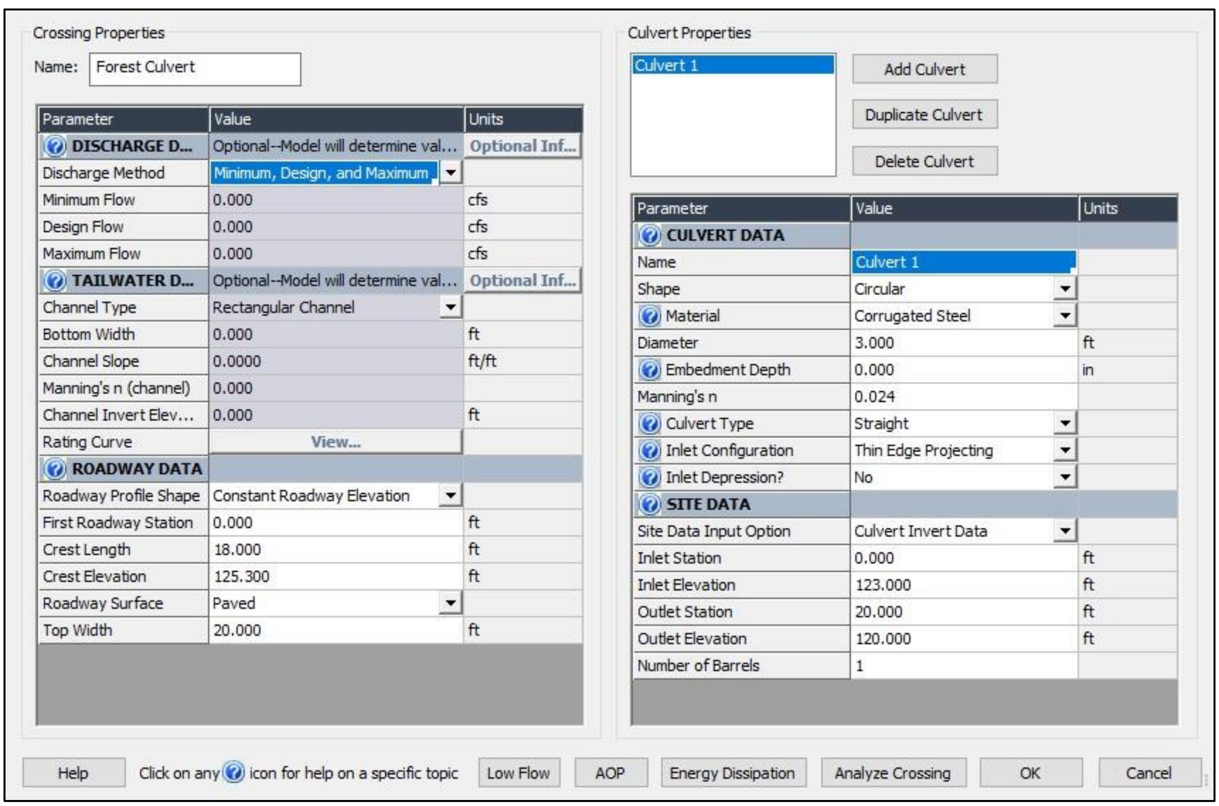


Figure 29: Forest Culvert HY-8 culvert parameters

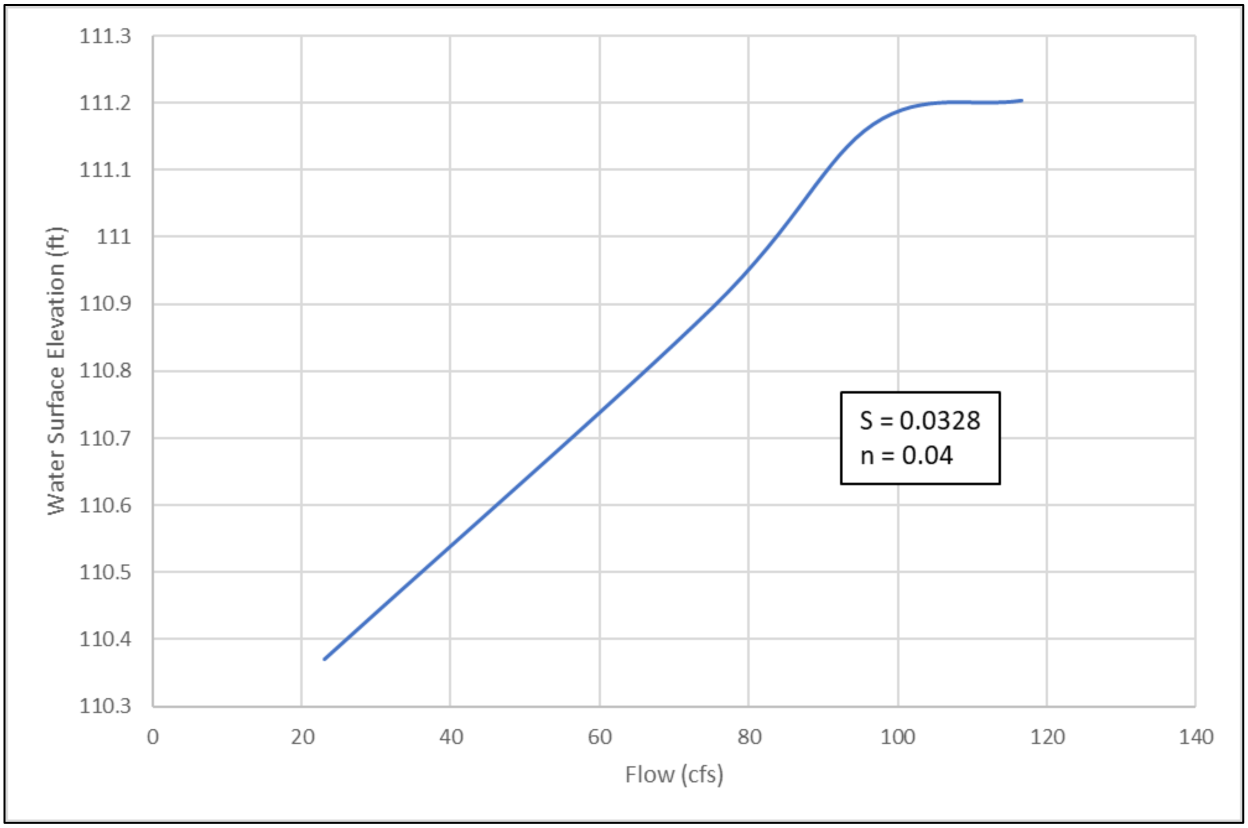


Figure 30: Downstream outflow boundary condition normal depth rating curve

5.1.5 Model Run Controls

The start and end time used in the SRH-2D model are 0 hours and 10 hours respectively. A time step of 0.5 seconds was used with a dry initial condition. The default turbulence model was used. The model reached steady state during the run time, as seen in Appendix I.

5.1.6 Model Assumptions and Limitations

The model assumes that there is no backwater effect from the confluence with Wildcat Creek on the crossing. Because the confluence is 470 feet downstream of the crossing, past an undersized culvert that likely has a larger effect on the hydraulics at the crossing, this was deemed an appropriate assumption.

5.2 Existing Conditions

Existing conditions modeling results are reported at three cross sections upstream and three downstream of the existing culvert. These locations are shown on Figure 31 and resulting data are summarized in Table 12.

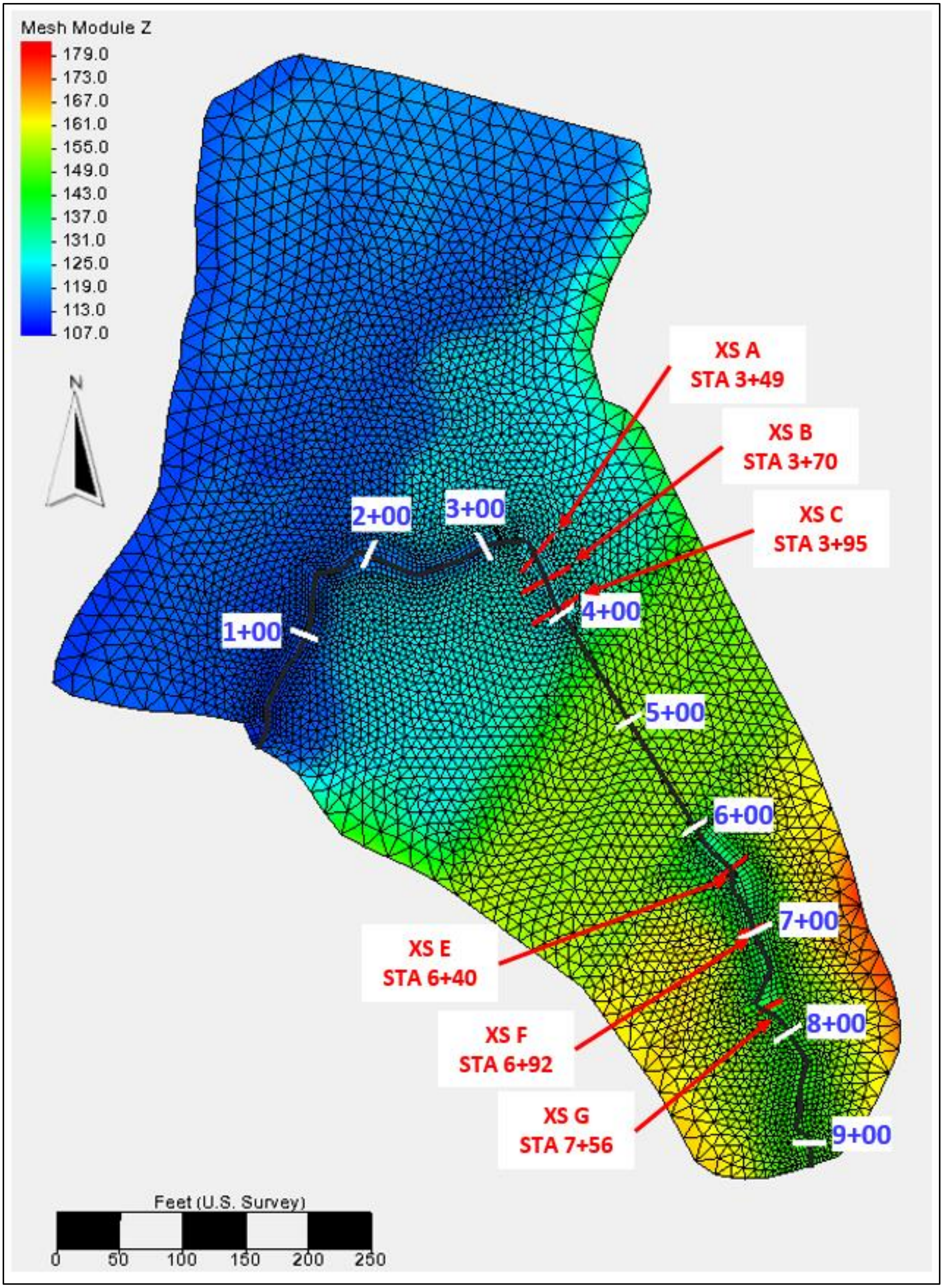


Figure 31: Locations of cross sections used for results reporting

Table 12: Average main channel hydraulic results for existing conditions

Hydraulic parameter	Cross section	2-year	100-year	500-year
Average WSE (ft)	DS 3+49 (A)	124.9	125.5	125.6
	DS 3+70 (B)	124.8	125.4	125.6
	DS 3+95 (C)	125.4	125.7	125.8
	Structure (D)	NA	NA	NA
	US 6+40 (E)	136.1	138.0	139.2
	US 6+92 (F)	138.5	139.1	139.3
	US 7+56 (G)	140.6	140.8	140.9
Max depth (ft)	DS 3+49 (A)	1.5	2.1	2.2
	DS 3+70 (B)	1.3	1.9	2.1
	DS 3+95 (C)	0.8	1.0	1.1
	Structure (D)	NA	NA	NA
	US 6+40 (E)	1.0	2.9	4.2
	US 6+92 (F)	0.8	1.3	1.6
	US 7+56 (G)	0.8	1.0	1.1
Average velocity (ft/s)	DS 3+49 (A)	1.2	2.5	3.0
	DS 3+70 (B)	1.4	2.9	3.4
	DS 3+95 (C)	4.9	7.8	8.7
	Structure (D)	NA	NA	NA
	US 6+40 (E)	2.9	2.2	1.6
	US 6+92 (F)	3.5	5.3	5.7
	US 7+56 (G)	3.2	5.3	5.9
Average shear (lb/SF)	DS 3+49 (A)	0.1	0.2	0.3
	DS 3+70 (B)	0.1	0.3	0.4
	DS 3+95 (C)	1.5	3.1	3.7
	Structure (D)	NA	NA	NA
	US 6+40 (E)	0.7	0.2	0.1
	US 6+92 (F)	1.1	1.7	1.9
	US 7+56 (G)	2.1	4.3	5.0

Main channel extents were approximated by inspection of channel banks in the topography.

The SRH-2D model results show that the existing Culvert 993724 creates a flow constriction that produces backwatering upstream (Figure 32). Therefore, Culvert 993724 is undersized for the flow in the unnamed tributary for any flood event greater than 2-year. SR 8 is not overtopped by the backwater, but the channel bed on either end of the culvert has been affected. Velocity ratios between the culvert inlet and outlet are 0.4 or lower during 100- and 500-year flows, illustrating the potential for erosive flows exiting the culvert (Table 12). The longitudinal extent of the impact of the undersized culvert is indicated by the difference in the average in-channel flow velocities approximately 30 feet upstream and downstream. Flows have a higher velocity upstream of the culvert and slow upon entering the backwater at the culvert inlet (Figure 34). Flow velocity increases with distance through the culvert.

Accurately capturing the dynamics of the smaller Forest Culvert for the largest flows was difficult for the numerical model. This relates to flow overtopping the right bank just upstream of the Forest Culvert and circumventing this culvert (Figure 34). Earlier SRH-2D modeling completed by Herrera indicates that these occurrences make the connection between SRH-2D and HY-8 unstable. However, this issue appears to have only a small impact on the model results. The Forest Culvert is far enough downstream of Culvert 994773 that hydraulics at the Forest Culvert do not influence flow at Culvert 994773. The overflow is also limited to a small volume. The confluence with the much larger Wildcat Creek has a much larger influence over the downstream model boundary. See Appendix H for detailed model results.

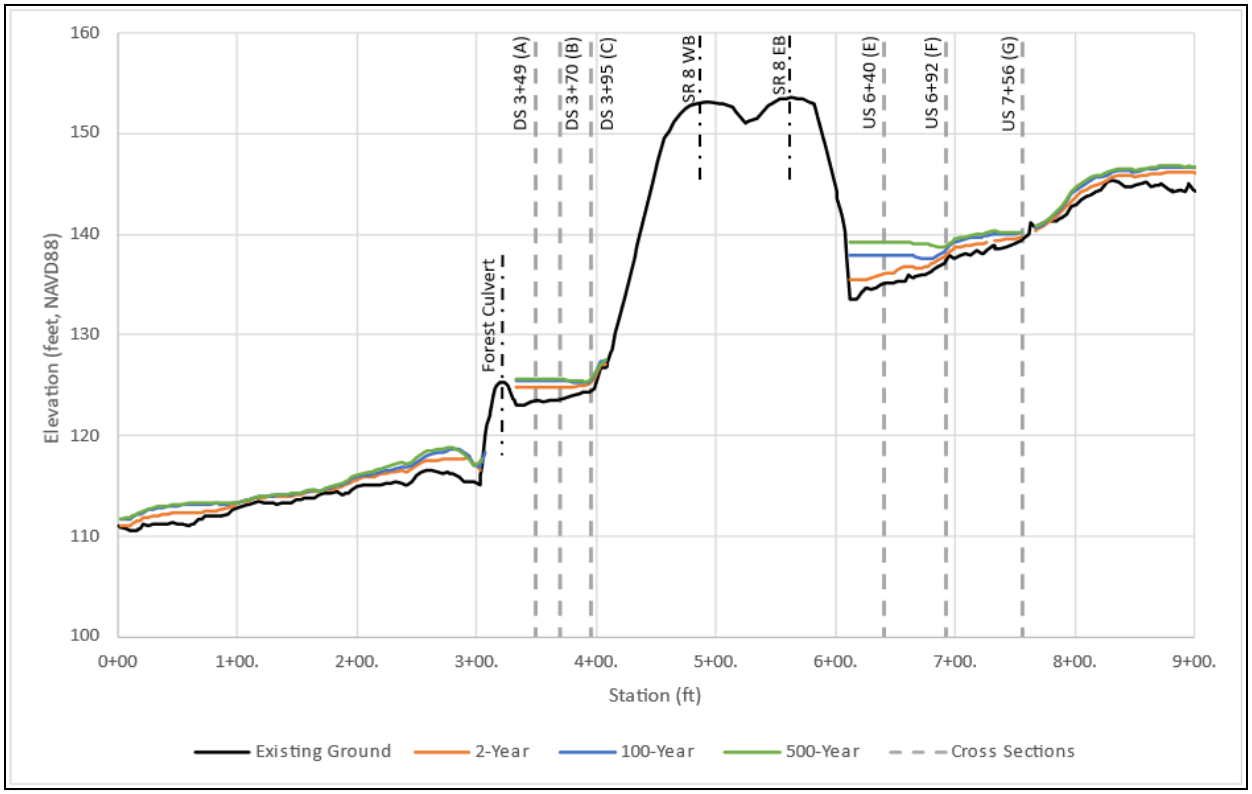


Figure 32: Existing-conditions water surface profiles

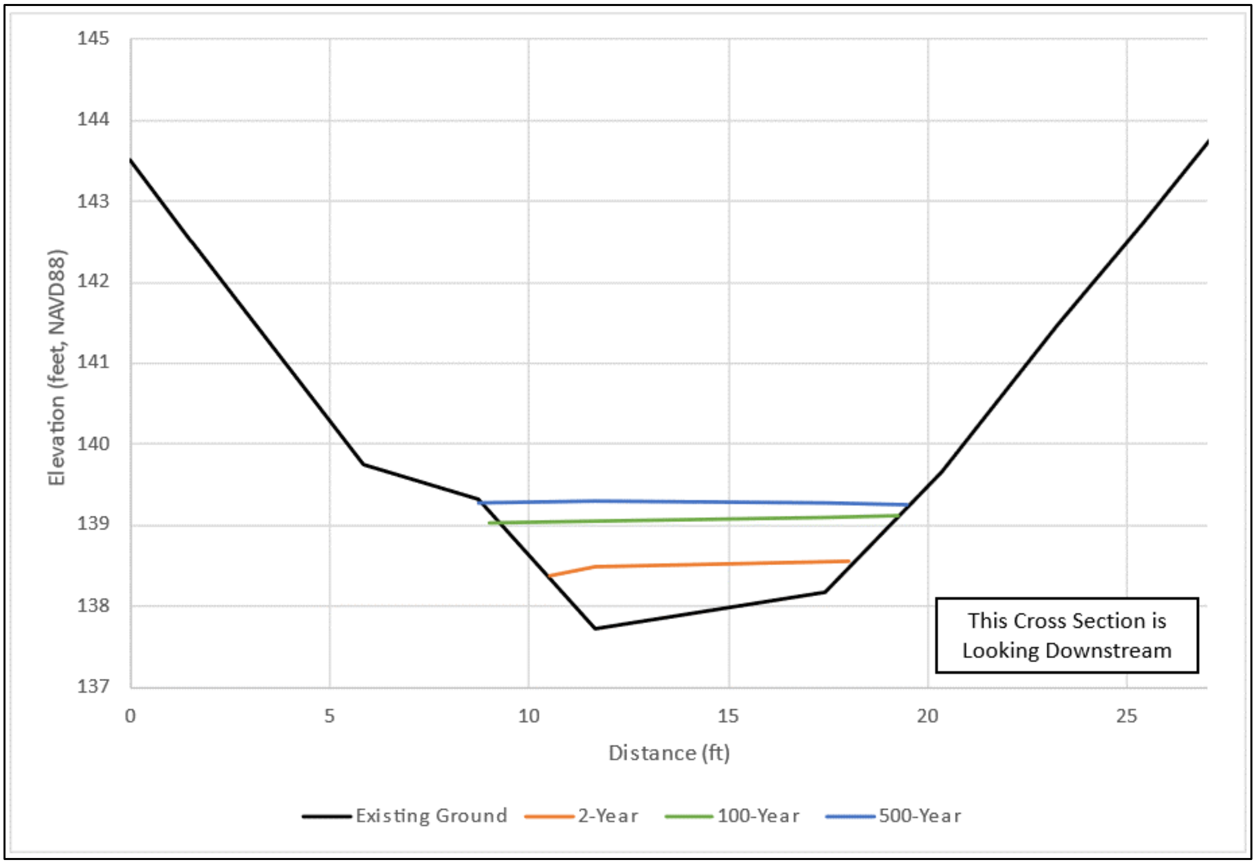


Figure 33: Typical existing channel cross section upstream of SR 8 (STA 6+92)

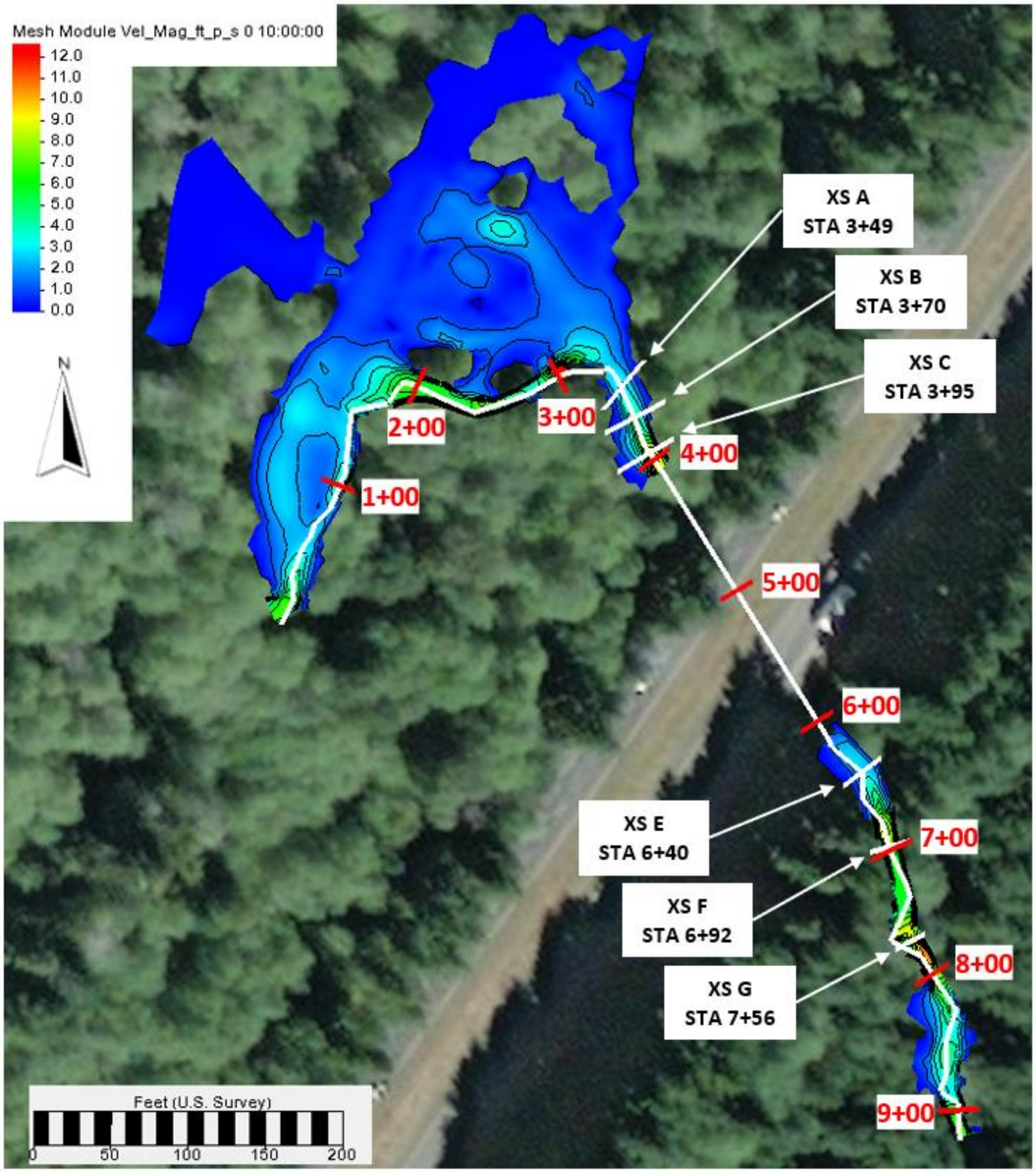


Figure 34: Existing-conditions 100-year velocity map with cross-section locations

Table 13: Existing-conditions average channel and floodplains velocities

Cross-section location	Q100 average velocities tributary scenario (ft/s)		
	LOB[a]	Main channel	ROB[a]
DS 3+49 (A)	0.7	2.5	0.5
DS 3+70 (B)	0.5	2.9	0.6
DS 3+95 (C)	1.0	7.8	1.7
Structure (D)	NA	NA	NA
US 6+40 (E)	1.7	2.2	0.4
US 6+92 (F)	0.0	5.3	0.0
US 7+56 (G)	0.0	5.3	0.0

Right overbank (ROB)/left overbank (LOB) locations were approximated by inspection of channel banks in the topography.

5.3 Natural Conditions

A natural-conditions model was not required as the system is confined.

5.4 Proposed Conditions: 17-foot Minimum Hydraulic Width

The hydraulic width is defined as the width perpendicular to the creek beneath the proposed structure that is necessary to convey the design flow and allow for natural geomorphic processes. See Section 4.2.2 for a description of how the minimum hydraulic width was determined. For the Unnamed Tributary to Wildcat Creek, the proposed modeling includes the clear-span width under the proposed eastbound and westbound bridges, which is significantly wider than the 17-foot minimum hydraulic width.

The proposed conditions scenario simulated with SRH-2D modified the existing conditions topography to include the proposed channel grading. The proposed bridges feature a gradually sloped channel with a 9-foot bottom width approximating the reference reach BFW and 2H:1V side slopes and channel benches as described in Section 4.2. As with the existing conditions, modeling results are reported at three cross sections upstream and three cross sections downstream of the new bridges. These locations are same as those used for existing conditions and their locations are shown in Figure 35. Table 14 lists simulated water surface elevations and flow velocities from the future conditions model.

Inlet and outlet flow velocities are shown to increase for the 100-year flow event under the proposed condition. The increase indicates a free flowing, open channel hydraulic condition where the flow enters and leaves the bridge structure unimpeded, whereas the existing culvert restricts conveyance capacity in large floods (Figure 32). Under proposed conditions the model results show there will no longer be a backwater condition at the SR 8 crossing. Instead there will be a consistent water surface gradient upstream and through the proposed structures (Figure 36). The simulated downstream outlet velocity is similar to that simulated farther downstream in the system (Figure 38). Thus, the proposed condition creates a steady flow through the new crossing. Most significant is the ratio of inlet to outlet velocities. For the proposed condition, the velocity ratio is around 1. So, the proposed condition is not expected to create areas of sediment deposition or erosion within the bridge crossing and will maintain a natural open channel hydraulic condition through the crossing of SR 8.

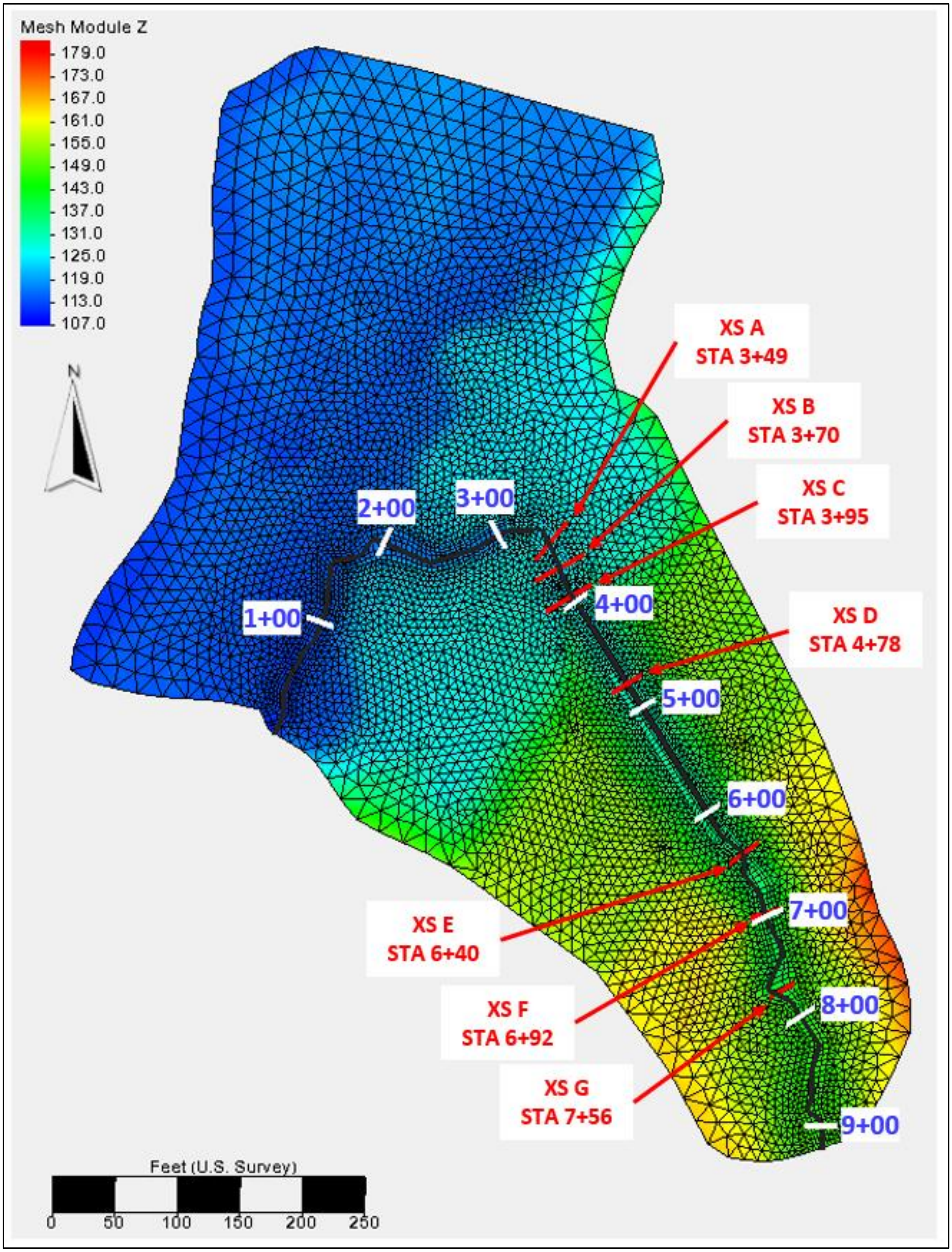


Figure 35: Locations of cross sections on proposed alignment used for results reporting

Table 14: Average main channel hydraulic results for proposed conditions

Hydraulic parameter	Cross section	2-year	100-year	Projected 2080 100-year	500-year
Average WSE (ft)	DS 3+49 (A)	124.9	125.5	125.7	125.6
	DS 3+70 (B)	124.8	125.4	125.7	125.6
	DS 3+95 (C)	125.9	126.6	126.9	126.7
	Structure 4+78 (D)	128.9	129.5	129.8	129.7
	US 6+40 (E)	135.8	136.5	136.9	136.7
	US 6+92 (F)	138.5	139.1	139.4	139.2
	US 7+56 (G)	140.6	140.8	141.0	140.9
Max depth (ft)	DS 3+49 (A)	1.5	2.1	2.3	2.2
	DS 3+70 (B)	1.3	1.9	2.2	2.1
	DS 3+95 (C)	1.2	1.9	2.2	2.1
	Structure 4+78 (D)	0.9	1.5	1.8	1.6
	US 6+40 (E)	1.1	1.8	2.2	2.0
	US 6+92 (F)	0.8	1.3	1.7	1.5
	US 7+56 (G)	0.8	1.0	1.1	1.1
Average velocity (ft/s)	DS 3+49 (A)	1.2	2.5	3.4	3.0
	DS 3+70 (B)	1.7	2.8	3.5	3.2
	DS 3+95 (C)	2.5	4.5	5.4	5.0
	Structure 4+78 (D)	3.8	4.5	6.0	5.4
	US 6+40 (E)	2.7	4.8	6.1	5.5
	US 6+92 (F)	3.5	5.3	6.3	5.9
	US 7+56 (G)	3.2	5.3	6.4	5.9
Average shear (lb/SF)	DS 3+49 (A)	0.1	0.2	0.4	0.3
	DS 3+70 (B)	0.2	0.4	0.5	0.4
	DS 3+95 (C)	1.9	3.4	4.5	4.0
	Structure 4+78 (D)	1.2	1.5	2.2	1.9
	US 6+40 (E)	2.3	4.7	6.1	5.3
	US 6+92 (F)	1.1	1.7	2.2	2.0
	US 7+56 (G)	2.1	4.3	5.5	5.0

Main channel extents were approximated by inspection of channel banks in the topography.

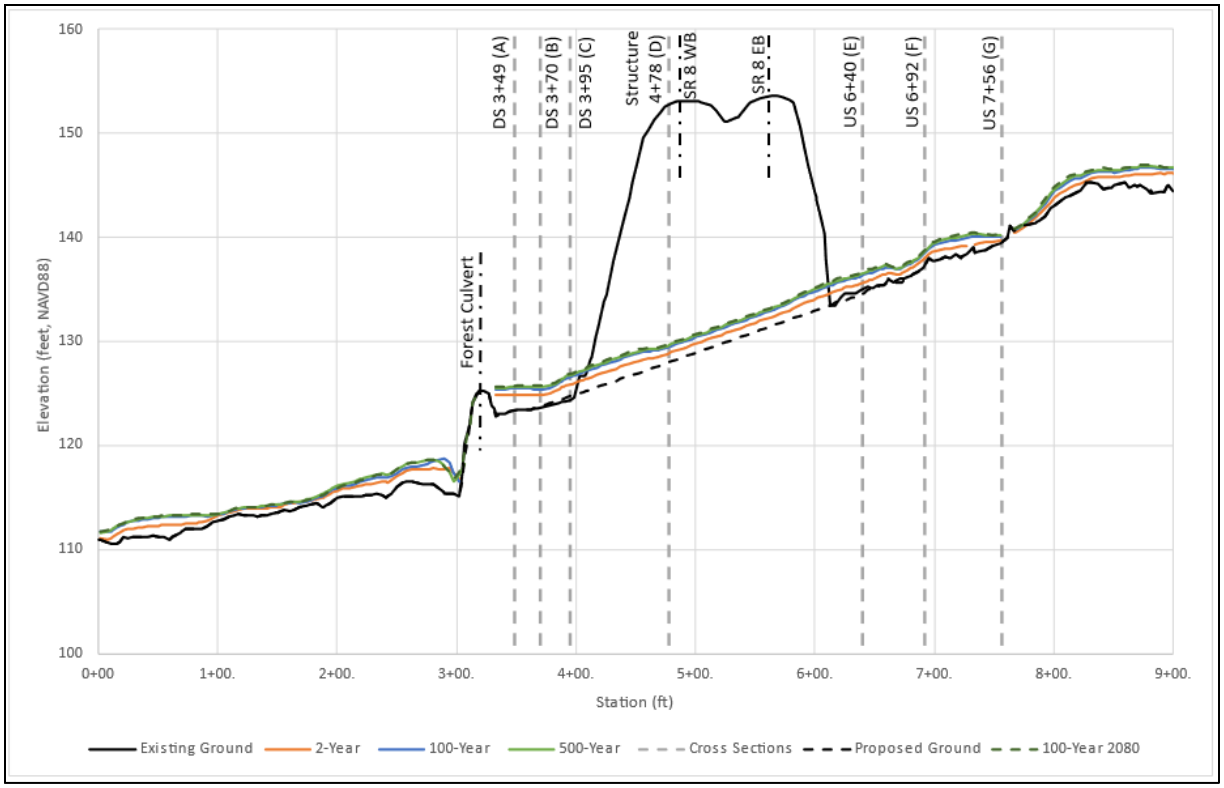


Figure 36: Proposed-conditions water surface profiles

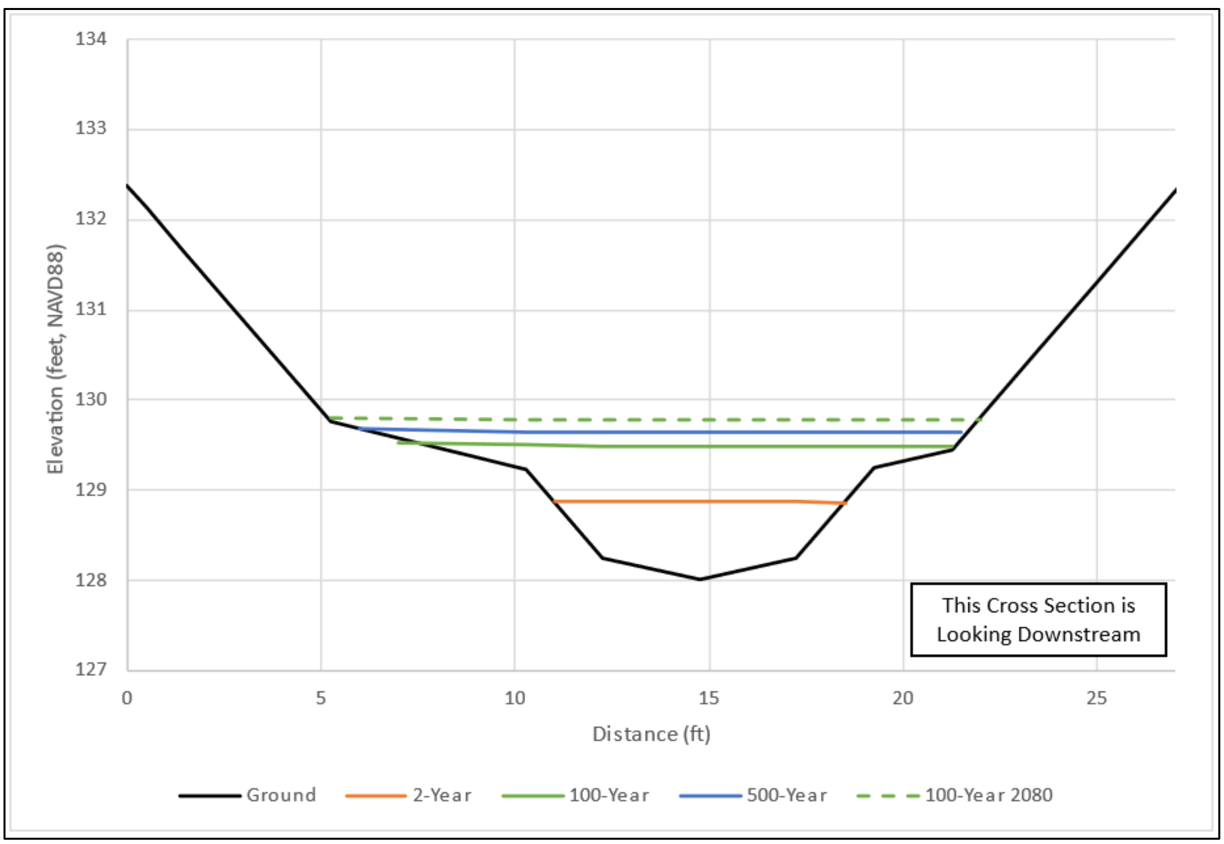


Figure 37: Typical section through proposed structure (STA 4+78)

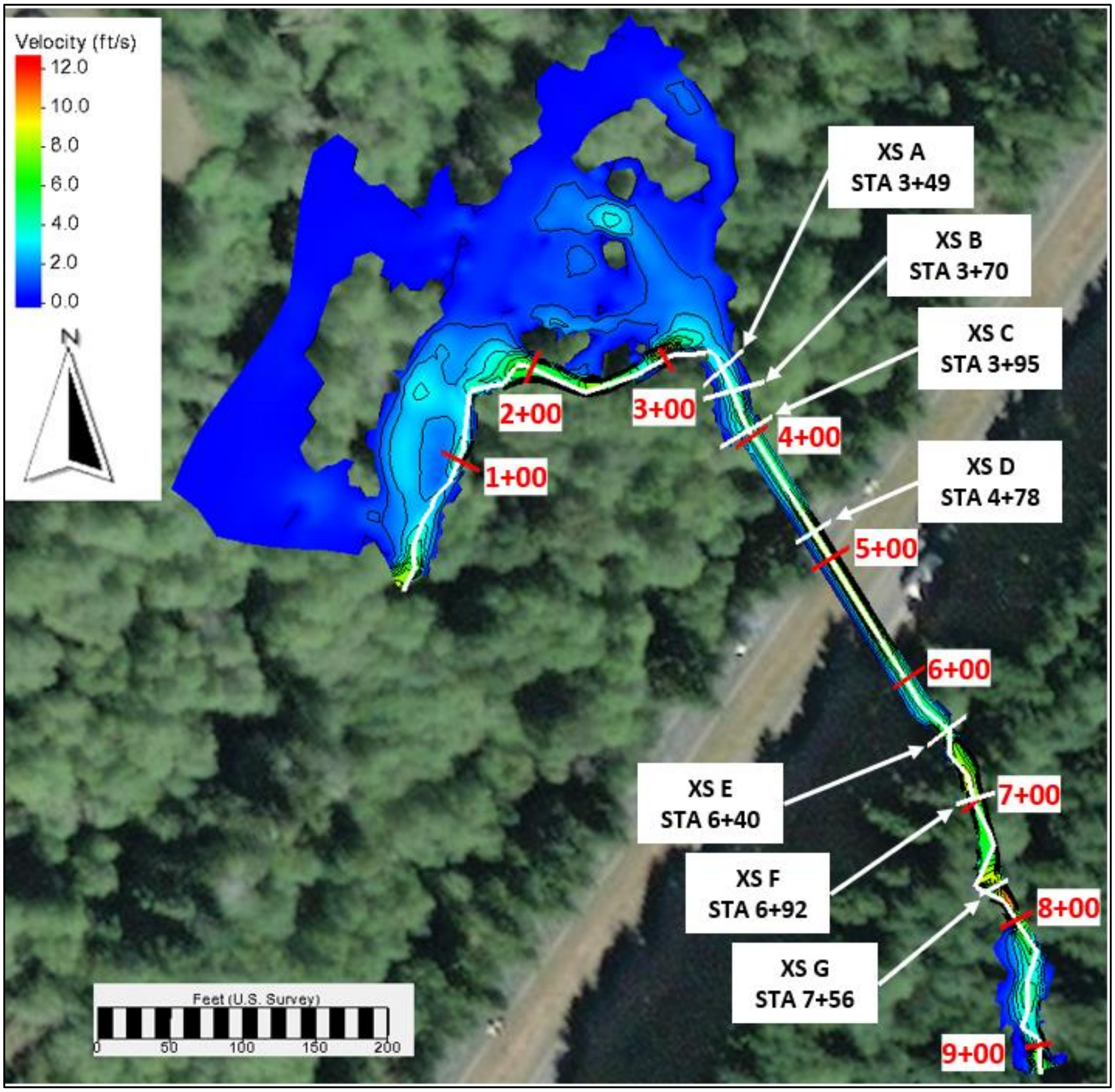


Figure 38: Proposed-conditions 100-year velocity map

Table 15: Proposed-conditions average channel and floodplains velocities

Cross-section location	Q100 average velocities (ft/s)			2080 Q100 average velocity (ft/s)		
	LOB[a]	Main channel	ROB[a]	LOB[a]	Main channel	ROB[a]
DS 3+49 (A)	0.7	2.5	0.4	1.4	3.4	0.7
DS 3+70 (B)	0.0	2.8	0.9	0.0	3.5	1.7
DS 3+95 (C)	1.6	4.5	1.3	1.7	5.4	1.5
Structure 4+78 (D)	0.0	4.5	0.0	0.0	6.0	0.0
US 6+40 (E)	0.0	4.8	0.0	0.0	6.1	2.4
US 6+92 (F)	0.0	5.3	0.0	0.0	6.3	0.0
US 7+56 (G)	0.0	5.3	0.0	0.0	6.4	0.0

Right overbank (ROB)/left overbank (LOB) locations were approximated by inspection of channel banks in the topography.

6 Floodplain Evaluation

This project is not within a FEMA special flood hazard area (SFHA). However, Wildcat Creek is designated a Zone A floodplain, without a defined base flood elevation (BFE). The FIRM, which became effective February 3, 2017, indicates the Zone A floodplain has a width of 375 feet straddling Wildcat Creek, within which is the confluence of the unnamed tributary. See Appendix A for the floodplain map.

Despite not being included in the Zone A mapped area, the existing-project and expected proposed-project conditions were evaluated to determine whether the project would cause a change in flood risk. The results of a comparison between the existing and proposed conditions 100-year WSE are shown in Figure 39. A large decrease in the water surface elevation is seen upstream of the crossing, indicating that the proposed crossing eliminates the backwater effect caused by the existing culvert. There is also some floodplain increase immediately downstream of the crossing. This is due to the proposed grading that fills in a scour hole downstream of the existing culvert. This increase is not a result of increased flow depth along the channel. Figure 39 also shows some incidental increases near Wildcat Creek in an area that is largely wetlands. The increases in this area are likely due to boundary effects in the modeling and are not necessarily a result of the project.

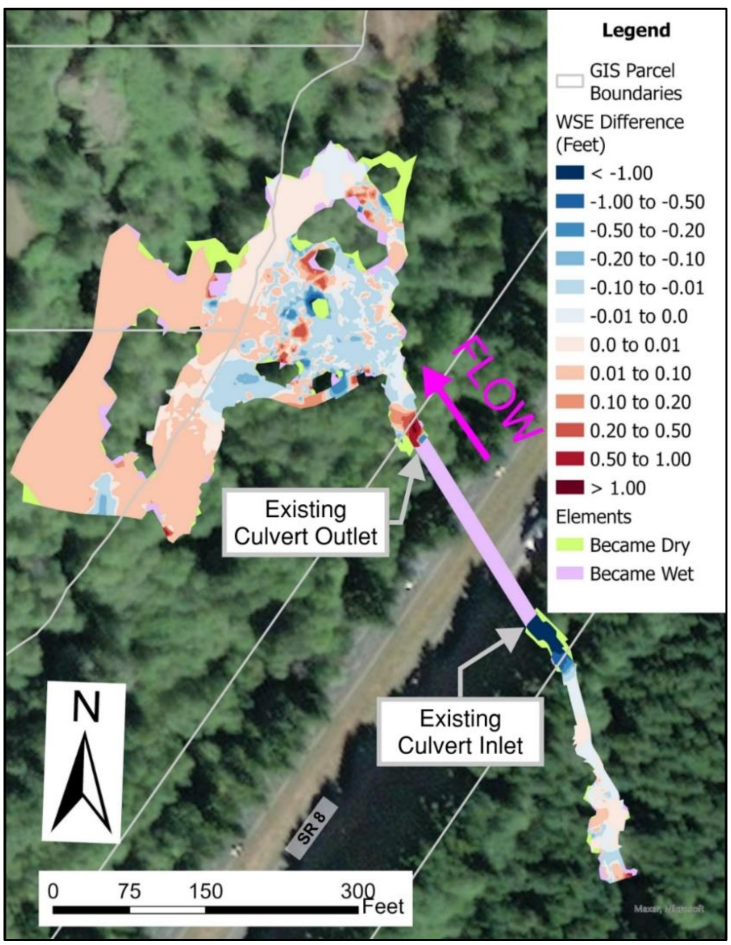


Figure 39: 100-year WSE change from existing to proposed conditions

7 Final Scour Analysis

For this FHD, the risk for lateral migration, potential for long-term degradation, and evaluation of total scour are based on the final geotechnical memo dated March 4, 2020.

Using the results of the hydraulic analysis (Section 5.4), based on the recommended final structure, and considering the potential for lateral channel migration, final scour calculations for the scour design flood, scour check flood, and 2080 projected 100-year were performed following the procedures outlined in *Evaluating Scour at Bridges, HEC No. 18* (Arneson et al. 2012). Scour components considered in the analysis include:

- Long-term degradation
- Contraction scour
- Local scour

In addition to the three scour components listed above, the potential for lateral migration was assessed to evaluate total scour at the proposed highway infrastructure. These various scour components will be discussed in the following sections.

7.1 Lateral Migration

The WCDG requires that bridges account for lateral channel movement that can occur in their design life and that the design channel maintains floodplain continuity. The geotechnical report for this project found that the materials at the site are erodible, so migration is possible. However, as previously discussed, the channel is in a natural ravine, is naturally steep and confined, and is unlikely to undergo significant lateral migration especially for any scenario where the downstream Forest Culvert is removed from the longitudinal channel profile. The existing floodplain width of the unnamed stream is relatively small upstream and downstream of SR 8. So, the risk of lateral migration is low and, therefore, the risk to the bridge structure due to lateral channel migration both upstream and through the structure is low.

In the unlikely case of lateral migration to one of the bridge abutments, abutment scour has been calculated for this scenario and is discussed in Section 7.4. If the channel does migrate, the LWM and boulder clusters will guide migration.

7.2 Long-term Degradation of the Channel Bed

Long-term streambed elevation changes associated with man-made or natural causes are considered long-term aggradation and degradation. Aggradation is the deposition of material upstream of a road crossing caused by erosion of the channel and/or upstream watershed. Aggradation is not a component of total scour. Conversely, degradation is the lowering or scouring of the channel bed across long reaches of channel caused by a decrease in the sediment supply from upstream and/or removal of a channel grade control feature(s) downstream. Degradation is a component of total scour.

At SR 8 MP 3.16 Unnamed Tributary to Wildcat Creek both aggradation and degradation may occur at different times due to different processes. Long-term degradation was estimated based on an analysis of the stream profile and an assessment of the geomorphic change that could occur due to the removal or failure of the Forest Culvert downstream of SR 8.

The analysis of aggradation potential adopts a simple graphical projection of the equilibrium thalweg profile (green line in Figure 40). The Forest Culvert is currently undersized from both a hydraulics and geomorphic point of view. Given that sediment supply in this stream is intact, and the project site is located amid a confluence alluvial fan, ongoing sediment accumulation upstream of the Forest Culvert can be expected until it fails or is replaced. Plugging of the Forest Culvert with debris would exacerbate the accumulation of sediment upstream of this culvert trapping potentially large quantities of sediment in the project reach. The extreme scenario under a condition where the Forest Culvert is completely blocked is that sediment could accumulate up to height of the road over the Forest Culvert. This scenario could result in up to 2.3 feet of additional sediment accumulating at the Forest Culvert and extending upstream through the SR 8 crossing. However, this scenario is very low risk because the Forest Culvert has been in place for many years with little sediment accumulation inside the pipe. If in the unlikely case that this does happen, the freeboard under the proposed SR 8 bridges would still exceed minimum requirements.

The more likely scenario of degradation adopts the same profile-type approach. In this case, it is assumed that equilibrium would be achieved between the upstream extent of proposed grading and the tailout of the scour pool associated with the Forest Culvert. This scenario also assumes the Forest Culvert is either intentionally replaced or fails without any grade control. The small accumulation of material currently upstream of the SR 8 crossing will be removed during construction and is not expected to reaccumulate, unless impeded by the Forest Culvert. Therefore, the equilibrium degradation profile yields little to no scour at the upstream end of the new crossing and approximately 2.5 feet of scour at the downstream end of the proposed crossing. Further examination of the stream channel profile leads to a conclusion that the scour hole downstream of the Forest Culvert would likely fill in (or be filled in), regardless of whether that culvert fails or is intentionally replaced.

After the Forest Culvert's failure or replacement, over time, the channel would start to aggrade again (being in an alluvial fan). However, it is very important to realize that this aggradation process would take many decades, possibly even centuries, to result in aggradation up to the historical streambed elevations and current aggraded elevations that developed due to the Forest Culvert.

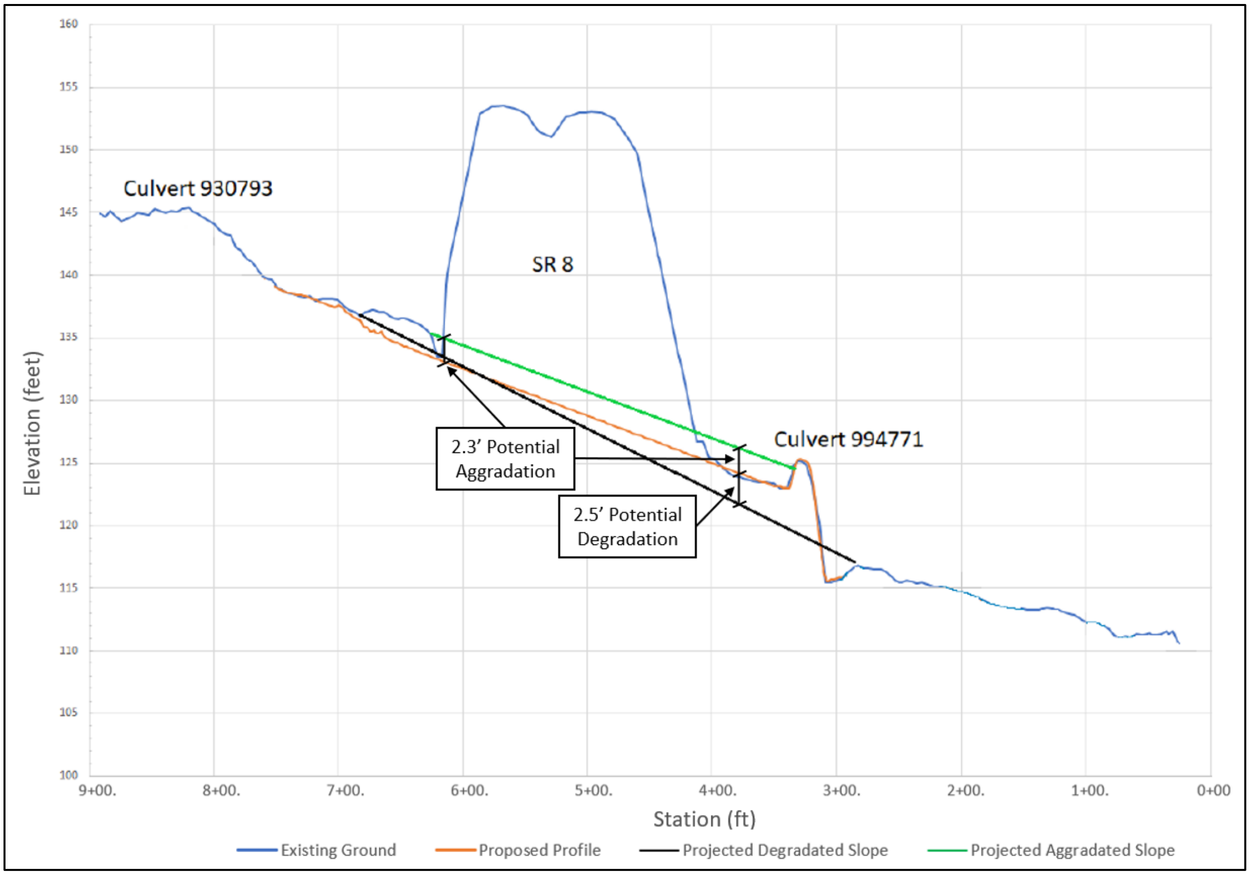


Figure 40: Potential long-term aggradation and degradation along the stream profile

7.3 Contraction Scour

An analysis of potential contraction scour was completed in the federal Highway Administration's (FHWA's) Hydraulic Toolbox Version 5.1. The analysis was live-bed for all conditions. Contraction scour equations estimate depths of scour at the eastbound structure of 0.0 feet, 0.1 feet, and 0.4 feet at the scour design flood, scour check flood, and 2080 projected 100-year flood, respectively. At the westbound structure, scour equations estimate that no contraction scour will occur. Detailed scour calculations are provided in Appendix K.

7.4 Local Scour

7.4.1 Pier Scour

The crossing will not have piers and therefore pier scour was not calculated

7.4.2 Abutment Scour

Abutment scour was estimated using the National Cooperative Highway Research Program (NCHRP) 24-20 approach for the scour design flood and scour check flood. A vertical wall was assumed for the calculations.

Abutment scour equations estimate depths of scour at the eastbound structure of 0.3 feet, 0.2 feet, and 0.4 feet at the scour design flood, scour check flood, and 2080 projected 100-year flood, respectively. At the westbound structure, abutment scour equations estimate depths of scour at the eastbound structure of 0.3 feet, 0.1 feet, and 0.3 feet at the scour design flood, scour check flood, and 2080 projected 100-year flood, respectively. Abutment scour calculated using the NCHRP methodology includes contraction scour, therefore contraction scour is not added to total scour since it is part of abutment scour. Detailed scour calculations are provided in Appendix K.

7.4.3 Bend scour

Bend scour was not quantified at this crossing given the lack of anticipated bends in the vicinity of the crossing.

7.5 Total Scour

Calculated total depths of scour for the scour design flood and scour check flood at the proposed unnamed tributary to Wildcat Creek eastbound and westbound bridges as will be shown on the final design plans, are provided in Table 16. HQ Hydraulics recommends that each infrastructure component be designed to account for the depths of scour provided in Table 16.

Table 16: Scour analysis summary

Calculated Scour Components and Total Scour for SR 8 UNT to Wildcat Creek						
	Eastbound Bridge			Westbound Bridge		
	Scour design flood	Scour check flood	2080 Projected 100-year flood	Scour design flood	Scour check flood	2080 Projected 100-year flood
Long-term degradation (ft)	0.0	0.0	0.0	2.5	2.5	2.5
Contraction scour (ft)	0.0	0.1	0.4	0.0	0.0	0.0
Local scour (ft)	0.3	0.2	0.4	0.3	0.1	0.3
Total depth of scour (ft)	0.3	0.2	0.4	2.8	2.6	2.8

8 Scour Countermeasures

In order to protect the bridge abutments from potential scour, rock for erosion and scour protection class A (WSDOT specification 9-13.4(2)) will be buried outside the limits of the hydraulic opening. The buried revetment material sizing calculations are included in Appendix M. The buried revetment design is shown in Figure 41 and Figure 20 shows the design relative to the structure free zone. The buried revetment begins at the edge of the hydraulic opening 3 feet below the thalweg. This depth is greater than the anticipated degradation and scour. The buried revetment extends outwards from the edge of the hydraulic opening towards the abutments until it reaches 2 feet above the 100-year WSE. Appendix D shows a plan view of the buried revetment location, which wraps around the bridge abutments.

No filter was determined to be necessary due to the size of material. In addition, a filter blanket is not practical for this design because the revetment is buried. To keep soil from piping into the revetment rock, the filter blanket would have to be installed both above and below the revetment. If the revetment were to become exposed, then there would be filter blanket material on the surface. Therefore, it is more practical to leave out the filter blanket.

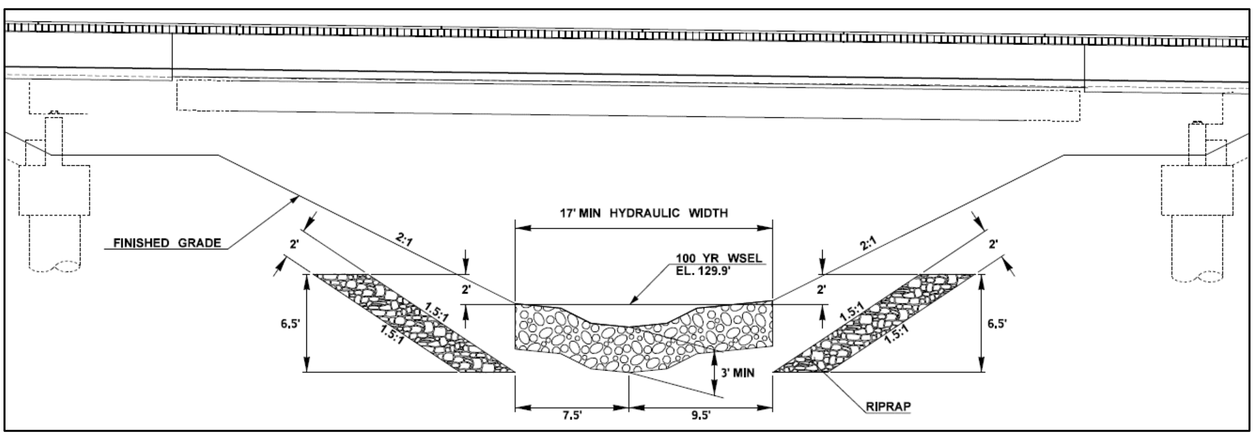


Figure 41: Buried revetment design

9 Summary

Table 17 presents a summary of the results of this PHD Report.

Table 17: Report summary

Stream crossing category	Element	Value	Report location
Habitat gain	Total length	7392 LF	2.1 Site Description
Bankfull width	Reference reach found?	Yes	2.7.1 Reference Reach Selection
	Design BFW	9.1 ft	2.7.2 Channel Geometry
	Concurrence BFW	9.1 ft	2.7.2 Channel Geometry
Floodplain utilization ratio (FUR)	Flood-prone width	18.11 ft	2.7.2.1 Floodplain Utilization Ratio
	Average FUR	1.53	2.7.2.1 Floodplain Utilization Ratio
Channel morphology	Existing	See link	2.7.2 Channel Geometry
	Proposed	See link	4.3.2 Channel Complexity
Hydrology/design flows	100 yr flow	75.1 cfs	3 Hydrology and Peak Flow Estimates
	2080 100 yr flow	116.6 cfs	3 Hydrology and Peak Flow Estimates
	2080 100 yr used for design	Yes	3 Hydrology and Peak Flow Estimates
	Dry channel in summer	No	3 Hydrology and Peak Flow Estimates
Channel geometry	Existing	See link	2.7.2 Channel Geometry
	Proposed	See link	4.1.1 Channel Planform and Shape
Channel slope/gradient	Existing culvert	3.4%	2.6.2 Existing Conditions
	Reference reach	3.3%	2.7.1 Reference Reach Selection
	Proposed	4.02%	4.1.3 Channel Gradient
Hydraulic width	Existing	4 ft	2.6.2 Existing Conditions
	Proposed	17 ft	4.2.2 Hydraulic Width
	Added for climate resilience	No	4.2.2 Hydraulic Width
Vertical clearance	Required freeboard	2 ft	4.2.3 Vertical Clearance
	Required freeboard applied to 100 yr or 2080 100 yr	2080 100 yr	4.2.3 Vertical Clearance
	Maintenance clearance	Recommended 6 ft	4.2.3 Vertical Clearance
	Low chord elevation	See link	4.2.3 Vertical Clearance
Crossing length	Existing	204 ft	2.6.2 Existing Conditions
	Proposed	121 ft	4.2.4 Hydraulic Length
Structure type	Recommendation	Yes	4.2.6 Structure Type
	Type	Bridge	4.2.6 Structure Type
Substrate	Existing	See link	2.7.3 Sediment
	Proposed	See link	4.3.1 Bed Material
	Coarser than existing?	Yes	4.3.1 Bed Material
Channel complexity	LWM for bank stability	No	4.3.2 Channel Complexity
	LWM for habitat	Yes	4.3.2 Channel Complexity
	LWM within structure	No	4.3.2 Channel Complexity
	Meander bars	None	4.3.2 Channel Complexity
	Boulder clusters	4	4.3.2 Channel Complexity
	Coarse bands	None	4.3.2 Channel Complexity

Stream crossing category	Element	Value	Report location
	Mobile wood	No	4.3.2 Channel Complexity
Floodplain continuity	FEMA mapped floodplain	No	6 Floodplain Evaluation
	Lateral migration	No	2.7.5 Channel Migration
	Floodplain changes?	No	6 Floodplain Evaluation
Scour	Analysis	See link	7 Final Scour Analysis
	Scour countermeasures	Yes	8 Scour Countermeasures
Channel degradation	Potential?	0.5-2.5 feet	7.2 Long-term Degradation of the Channel Bed
Channel degradation	Allowed?	Yes	7.2 Long-term Degradation of the Channel Bed

References

Aquaveo. 2021. SMS Version 13.1.15.

Arneson, L.A., L.W. Zevenbergen, P.F. Lagasse, P.E. Clopper. 2012. Evaluating Scour at Bridges—Fifth Edition. Federal Highway Administration. Fort Collins, Colorado. Publication FHWA-HIF-12-003 (HEC No. 18).

Barnard, R.J., J. Johnson, P. Brooks, K.M. Bates, B. Heiner, J.P. Klavas, D.C. Ponder, P.D. Smith, and P.D. Powers. 2013. *Water Crossing Design Guidelines*. Washington State Department of Fish and Wildlife. Olympia, Washington.

Chow, V.T. 1959. Open Channel Hydraulics, McGraw-Hill Book Company, New York.

Hart Crowser. 1994. Hydrogeologic Characterization for Protection of the Wildcat Creek Aquifer, Grays Harbor County, Washington. Prepared for City of McCleary. Washington Centennial lear Water Fund

Grant G93. Hart Crowser Report J-3500-01.

Fox, Martin and Bolton, Susan. 2007. *A Regional and Geomorphic Reference for Quantities and Volumes of Instream Wood in Unmanaged Forests Basins of Washington Stat. North American Journal of Fisheries Management.* Vol. 27, Issue 1. Pg. 342–359.

Lagasse, P.F., P.E. Clopper, J.E. Pagan-Ortiz, L.W. Zevenbergen, L.A. Arneson, J.D. Schall, L.G. Girard. 2009. *Bridge Scour and Stream Instability Countermeasures: Experience, Selection, and Design Guidance—Third Edition*. Federal Highway Administration. Fort Collins, Colorado. Publication FHWA-NHI-09-111.

Mastin, M.C., Konrad, C.P., Veilleux, A.G., and Tecca, A.E. 2016. Magnitude, frequency, and trends of floods at gaged and ungaged sites in Washington, based on data through water year 2014 (ver. 1.2, November 2017): U.S. Geological Survey Scientific Investigations Report 2016-5118, 70 p., http://dx.doi.org/10.3133/sir20165118.

Schanz, R., and K. Zirkle. 2007. Site and Reach Assessment Middle Fork Wildcat Creek at SR 8, MP 5.01 Bridge No. 8/13. WSDOT Environmental Services Program. Washington State Department of Transportation, Olympia, Washington.

Sumioka, S.S., Kresch, D.L., and Kasnick, K.D. 1998. Magnitude and Frequency of Floods in Washington: US Geological Survey Water-Resources Investigations Report. United States Geological Survey. Tacoma, Washington

USBR (United States Department of the Interior, Bureau of Reclamation). 1984. “Computing Degradation and Local Scour, Technical Guideline for Bureau of Reclamation.” Denver, Colorado.

USBR. 2017. SRH-2D Version 3.2.4.

USDA (United States Department of Agriculture). 2001. *Sampling Surface and Subsurface Particle-Size Distributions in Wadable Gravel- and Cobble-Bed Streams for Analyses in Sediment Transport, Hydraulics, and Streambed Monitoring.*

USDA. 2008. *Stream Simulation: An Ecological Approach to Providing Passage for Aquatic Organisms at Road-Stream Crossings, Appendix E.*

USGS (United States Geological Survey). 2016. The StreamStats program, online at http://streamstats.usgs.gov, accessed on 2019.

WDFW (Washington Department of Fish and Wildlife). 2019. *Fish Passage and Surface Water Diversion Screening Assessment and Prioritization Manual.* Olympia, Washington.

WDFW. 2022. Habitat Assessment Data for Unnamed Tributary to Wildcat Creek (culvert 993724) at SR 8 MP 3.16. Unpublished.

WDFW. 2022. Washington State Fish Passage. Website accessed online: https://geodataservices.wdfw.wa.gov/hp/fishpassage/index.html

WDFW. 2022. SCoRE (Salmon Conservation and Reporting Engine). Website accessed online: https://fortress.wa.gov/dfw/score/score/recovery/recovery.jsp#score

Washington Department of Fisheries. 1975. A Catalog of Washington Streams and Salmon Utilization. 4 Volumes. Olympia, Washington.

WSDOT (Washington State Department of Transportation). 2022a. *Hydraulics Manual*. Olympia, Washington. Publication M 23-03.06.

WSDOT. 2022b. *Standard Specifications for Road, Bridge, and Municipal Construction*. Olympia, Washington. Publication M 41-10.

WSDOT. 2020. Wildlife Habitat Connectivity and the Unnamed Tributary to Wildcat Creek (Site 993724), State Route 8. Unpublished.

Appendices

Appendix A: FEMA Floodplain Map

Appendix B: Hydraulic Field Report Form

Appendix C: Streambed Material Sizing Calculations

Appendix D: Stream Plan Sheets, Profile, Details

Appendix E: Manning's Calculations

Appendix F: Large Woody Material Calculations

Appendix G: Future Projections for Climate-Adapted Culvert Design

Appendix H: SRH-2D Model Results

Appendix I: SRH-2D Model Stability and Continuity

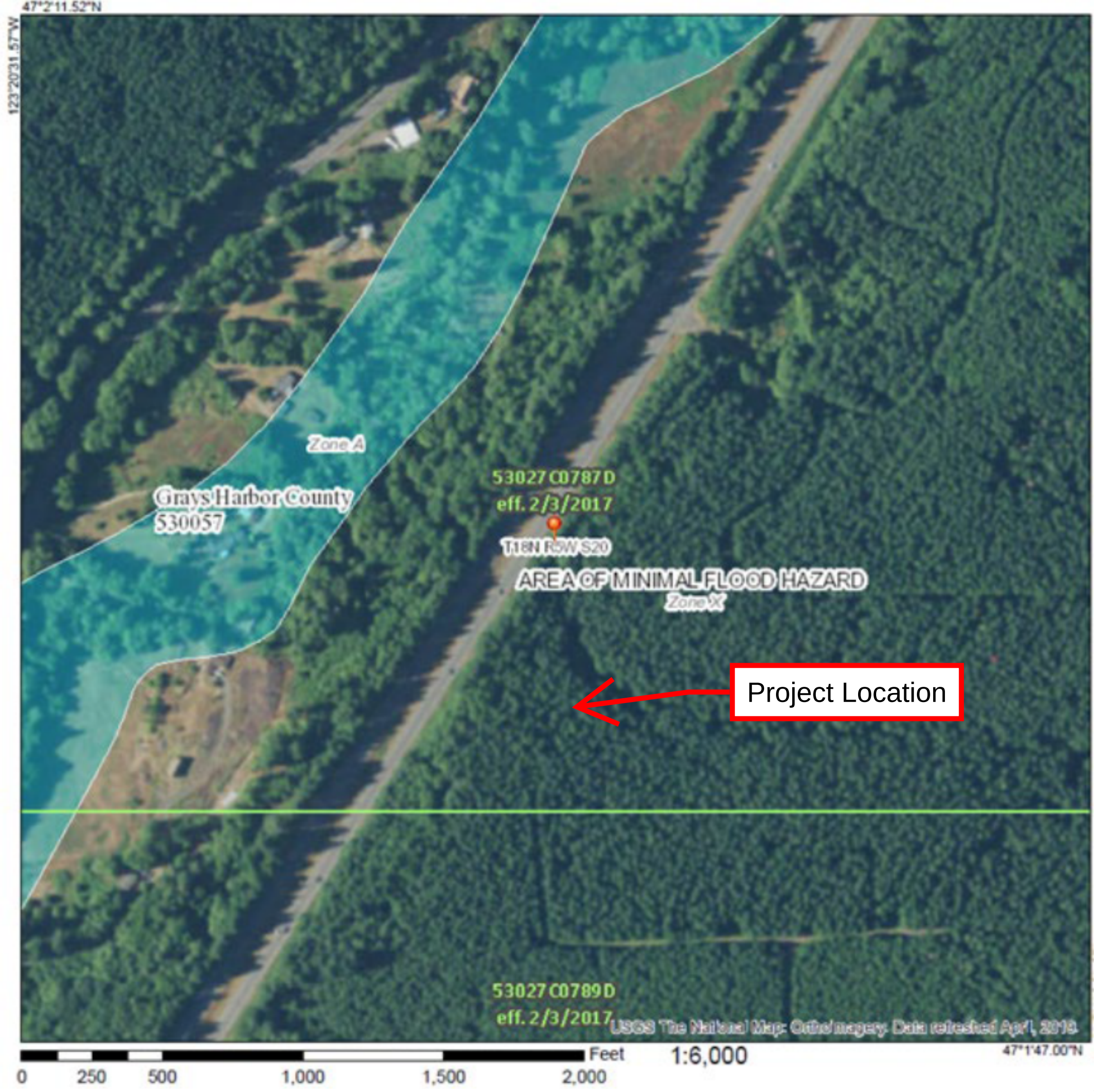
Appendix J: Reach Assessment

Appendix K: Scour Calculations

Appendix L: Floodplain Analysis

Appendix M: Scour Countermeasure Calculations

Appendix A: FEMA Floodplain Map



47°2'11.52"N
123°20'31.57"W
Zone A
Grays Harbor County
530057
53027C0787D
eff. 2/3/2017
T18N R5W S20
AREA OF MINIMAL FLOOD HAZARD
Zone X
Project Location
53027C0789D
eff. 2/3/2017
USGS The National Map: Orthoimagery. Data refreshed April, 2019.
47°1'47.00"N
Feet
1:6,000
0
250
500
1,000
1,500
2,000

NOTES TO USERS

This map is for use in administering the National Flood Insurance Program. It does not necessarily identify all areas subject to flooding, particularly from local drainage sources of small size. The **community map repository** should be consulted for possible updated or additional flood hazard information.

To obtain more detailed information in areas where **Base Flood Elevations** (BFEs) and/or **floodways** have been determined, users are encouraged to consult the Flood Profiles and Floodway Data and/or Summary of Stillwater Elevations tables contained within the Flood Insurance Study (FIS) Report that accompanies this FIRM. Users should be aware that BFEs shown on the FIRM represent rounded whole-foot elevations. These BFEs are intended for flood insurance rating purposes only and should not be used as the sole source of flood elevation information. Accordingly, flood elevation data presented in the FIS Report should be utilized in conjunction with the FIRM for purposes of construction and/or floodplain management.

Coastal Base Flood Elevations shown on this map apply only landward of 0.0' North American Vertical Datum of 1988 (NAVD 88). Users of this FIRM should be aware that coastal flood elevations are also provided in the Summary of Stillwater Elevations table in the Flood Insurance Study Report for this jurisdiction. Elevations shown in the Summary of Stillwater Elevations table should be used for construction and/or floodplain management purposes when they are higher than the elevations shown on this FIRM.

Boundaries of the **floodways** were computed at cross sections and interpolated between cross sections. The floodways were based on hydraulic considerations with regard to requirements of the National Flood Insurance Program. Floodway widths and other pertinent floodway data are provided in the Flood Insurance Study Report for this jurisdiction.

Certain areas not in Special Flood Hazard Areas may be protected by **flood control structures**. Refer to Section 2.4 "Flood Protection Measures" of the Flood Insurance Study Report for information on flood control structures for this jurisdiction.

The **projection** used in the preparation of this map was Universal Transverse Mercator (UTM) zone 10. The **horizontal datum** was NAD 83, GRS 1980 spheroid. Differences in datum, spheroid, projection or UTM zones used in the production of FIRMs for adjacent jurisdictions may result in slight positional differences in map features across jurisdiction boundaries. These differences do not affect the accuracy of this FIRM.

Flood elevations on this map are referenced to the North American Vertical Datum of 1988. These flood elevations must be compared to structure and ground elevations referenced to the same **vertical datum**. For information regarding conversion between the National Geodetic Vertical Datum of 1929 and the North American Vertical Datum of 1988, visit the National Geodetic Survey website at http://www.ngs.noaa.gov or contact the National Geodetic Survey at the following address:

NGS Information Services
NOAA, N/NGS12
National Geodetic Survey
SSMC-3, #9202
1315 East-West Highway
Silver Spring, Maryland 20910-3282
(301) 713-3242

To obtain current elevation, description, and/or location information for **bench marks** shown on this map, please contact the Information Services Branch of the National Geodetic Survey at **(301) 713- 3242**, or visit its website at http://www.ngs.noaa.gov.

Base map information shown on this FIRM was derived from multiple sources. Base map files were provided in digital format by Grays Harbor County GIS Department, WA DNR, and NGS. This information was compiled at various map scales during the time period 2004-2008.

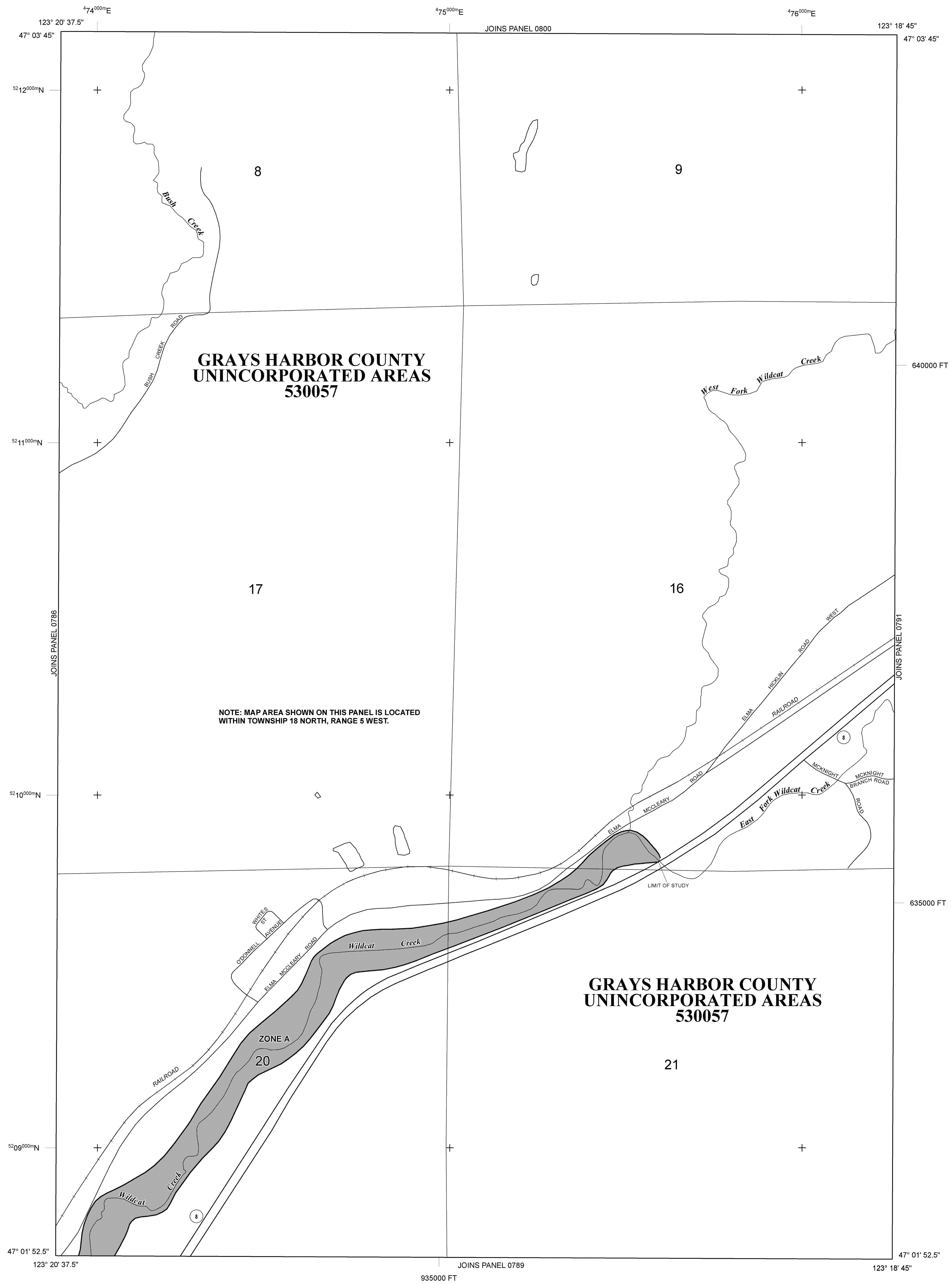
The **profile baselines** depicted on this map represent the hydraulic modeling baselines that match the flood profiles in the FIS report. As a result of improved topographic data, the **profile baseline**, in some cases, may deviate significantly from the channel centerline or appear outside the SFHA.

Corporate limits shown on this map are based on the best data available at the time of publication. Because changes due to annexations or de-annexations may have occurred after this map was published, map users should contact appropriate community officials to verify current corporate limit locations.

Please refer to the separately printed **Map Index** for an overview map of the county showing the layout of map panels; community map repository addresses; and a Listing of Communities table containing National Flood Insurance Program dates for each community as well as a listing of the panels on which each community is located.

For information on available products associated with this FIRM visit the **Map Service Center (MSC)** website at http://msc.fema.gov. Available products may include previously issued Letters of Map Change, a Flood Insurance Study Report, and/or digital versions of this map. Many of these products can be ordered or obtained directly from the MSC website.

If you have **questions about this map,** how to order products, or the National Flood Insurance Program in general, please call the **FEMA Map Information eXchange (FMIX)** at **1-877-FEMA-MAP** (1-877-336-2627) or visit the FEMA website at http://www.fema.gov/business/nfip.



LEGEND

SPECIAL FLOOD HAZARD AREAS (SFHAs) SUBJECT TO INUNDATION BY THE 1% ANNUAL CHANCE FLOOD

The 1% annual chance flood (100-year flood), also known as the base flood, is the flood that has a 1% chance of being equaled or exceeded in any given year. The Special Flood Hazard Area is the area subject to flooding by the 1% annual chance flood. Areas of Special Flood Hazard include Zones A, AE, AH, AO, AR, A99, V, and VE. The Base Flood Elevation is the water-surface elevation of the 1% annual chance flood.

ZONE A	No Base Flood Elevations determined.
ZONE AE	Base Flood Elevations determined.
ZONE AH	Flood depths of 1 to 3 feet (usually areas of ponding); Base Flood Elevations determined.
ZONE AO	Flood depths of 1 to 3 feet (usually sheet flow on sloping terrain); average depths determined. For areas of alluvial fan flooding, velocities also determined.
ZONE AR	Special Flood Hazard Areas formerly protected from the 1% annual chance flood by a flood control system that was subsequently decertified. Zone AR indicates that the former flood control system is being restored to provide protection from the 1% annual chance or greater flood.
ZONE A99	Area to be protected from 1% annual chance flood by a Federal flood protection system under construction; no Base Flood Elevations determined.
ZONE V	Coastal flood zone with velocity hazard (wave action); no Base Flood Elevations determined.
ZONE VE	Coastal flood zone with velocity hazard (wave action); Base Flood Elevations determined.

FLOODWAY AREAS IN ZONE AE

The floodway is the channel of a stream plus any adjacent floodplain areas that must be kept free of encroachment so that the 1% annual chance flood can be carried without substantial increases in flood heights.

OTHER FLOOD AREAS

ZONE X Areas of 0.2% annual chance flood; areas of 1% annual chance flood with average depths of less than 1 foot or with drainage areas less than 1 square mile; and areas protected by levees from 1% annual chance flood.

OTHER AREAS

ZONE X Areas determined to be outside the 0.2% annual chance floodplain.
ZONE D Areas in which flood hazards are undetermined, but possible.

COASTAL BARRIER RESOURCES SYSTEM (CBRS) AREAS

OTHERWISE PROTECTED AREAS (OPAs)

CBRS areas and OPAs are normally located within or adjacent to Special Flood Hazard Areas.

1% Annual Chance Floodplain Boundary
0.2% Annual Chance Floodplain Boundary
Floodway boundary
Zone D boundary
CBRS and OPA boundary
Boundary dividing Special Flood Hazard Area Zones and boundary dividing Special Flood Hazard Areas of different Base Flood Elevations, flood depths, or flood velocities.

~~ 513 ~~~	Base Flood Elevation line and value; elevation in feet*
(EL 987)	Base Flood Elevation value where uniform within zone; elevation in feet*

*Referenced to the North American Vertical Datum of 1988

A —— A	Cross section line
23 - - - - - 23	Transect line
45° 02' 08", 93° 02' 12"	Geographic coordinates referenced to the North American Datum of 1983 (NAD 83) Western Hemisphere
3100000 FT	5000-foot ticks: Washington State Plane South Zone (FIPS Zone 4602), Lambert Conformal Conic projection
$^{49}89^{000m}$ N	1000-meter Universal Transverse Mercator grid values, zone 10
DX5510 ×	Bench mark (see explanation in Notes to Users section of this FIRM panel)
• FT1,000	River Station

MAP REPOSITORIES
Refer to Map Repositories list on Map Index

EFFECTIVE DATE OF COUNTYWIDE
FLOOD INSURANCE RATE MAP
February 3, 2017

EFFECTIVE DATE(S) OF REVISION(S) TO THIS PANEL

For community map revision history prior to countywide mapping, refer to the Community Map History table located in the Flood Insurance Study report for this jurisdiction.

To determine if flood insurance is available in this community, contact your insurance agent or call the National Flood Insurance Program at 1-800-638-6620.

MAP SCALE 1" = 500'

250 0 500 1000 FEET
150 0 150 300 METERS

NFIP
NATIONAL FLOOD INSURANCE PROGRAM

PANEL 0787D

FIRM
FLOOD INSURANCE RATE MAP

GRAYS HARBOR, WASHINGTON
AND INCORPORATED AREAS

PANEL 787 OF 1295
(SEE MAP INDEX FOR FIRM PANEL LAYOUT)

CONTAINS:

COMMUNITY	NUMBER	PANEL	SUFFIX
GRAYS HARBOR COUNTY	530057	0787	D

Notice to User: The **Map Number** shown below should be used when placing map orders; the **Community Number** shown above should be used on insurance applications for the subject community.

MAP NUMBER
53027C0787D

EFFECTIVE DATE
FEBRUARY 3, 2017

Federal Emergency Management Agency

Appendix B: Hydraulic Field Report Form

A hydraulic field report form was never completed for this site because it was not required when the PHD was written.

Appendix C: Streambed Material Sizing Calculations

Summary - Stream Simulation Bed Material Design

Project:	Grays Harbor - Wildcat Creek
By:	Karen Comings, P.E.

Design Gradation:
Location: Proposed Channel

	D_{100}	D_{84}	D_{50}	D_{16}
ft	0.50	0.32	0.11	0.02
in	6.00	3.80	1.30	0.25
mm	152	97	33.0	6.4

Design Gradation:
Location: Upstream Pebble Count

	D_{100}	D_{84}	D_{50}	D_{16}
ft	0.59	0.18	0.09	0.06
in	7.10	2.10	1.10	0.70
mm	180	53	28	18

Design Gradation:
Location: Downstream Pebble Count

	D_{100}	D_{84}	D_{50}	D_{16}
ft	0.51	0.16	0.08	0.05
in	6.10	1.90	1.00	0.60
mm	155	48	25	15

Design Gradation:
Location:

	D_{100}	D_{84}	D_{50}	D_{16}
ft				
in				
mm				

Determining Aggregate Proportions

Per WSDOT Standard Specifications 9-03.11

Rock Size [in]	[mm]	Streambed Sediment	Streambed Cobbles 4"	6"	8"	10"	12"	Streambed Boulders 12"-18"	18"-28"	28"-36"	D_{size}
36.0	914									100	100.0
32.0	813									50	100.0
28.0	711								100		100.0
23.0	584								50		100.0
18.0	457							100			100.0
15.0	381							50			100.0
12.0	305						100				100.0
10.0	254					100	80				100.0
8.0	203				100	80	68				100.0
6.0	152			100	80	68	57				100.0
5.0	127			80	68	57	45				90.0
4.0	102		100	71	57	45	39				85.6
3.0	76.2		80	63	45	38	34				81.3
2.5	63.5	100	65	54	37	32	28				76.9
2.0	50.8	92.5	50	45	29	25	22				68.8
1.5	38.1	79	35	32	21	18	16				55.5
1.0	25.4	66	20	18	13	12	11				42.2
0.50	12.7	48	5	5	5	5	5				26.5
0.19	4.75	29									14.5
0.02	0.425	10									5.0
0.003	0.0750	5									2.5
% per category		50	0	50	0	0	0	0	0	0	--> 100%
% Cobble & Sediment		50.0	0.0	50.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0%

Streambed Mobility/Stability Analysis

Modified Shields Approach

References:

Stream Simulation: An Ecological Approach to Providing Passage for Aquatic Organizms at Road-Stream Crossings

Appendix E--Methods for Streambed Mobility/Stability Analysis

Limitations:

D_{84} must be between 0.40 in and 10 in

uniform bed material (Di < 20-30 times D50)

Slopes less than 5%

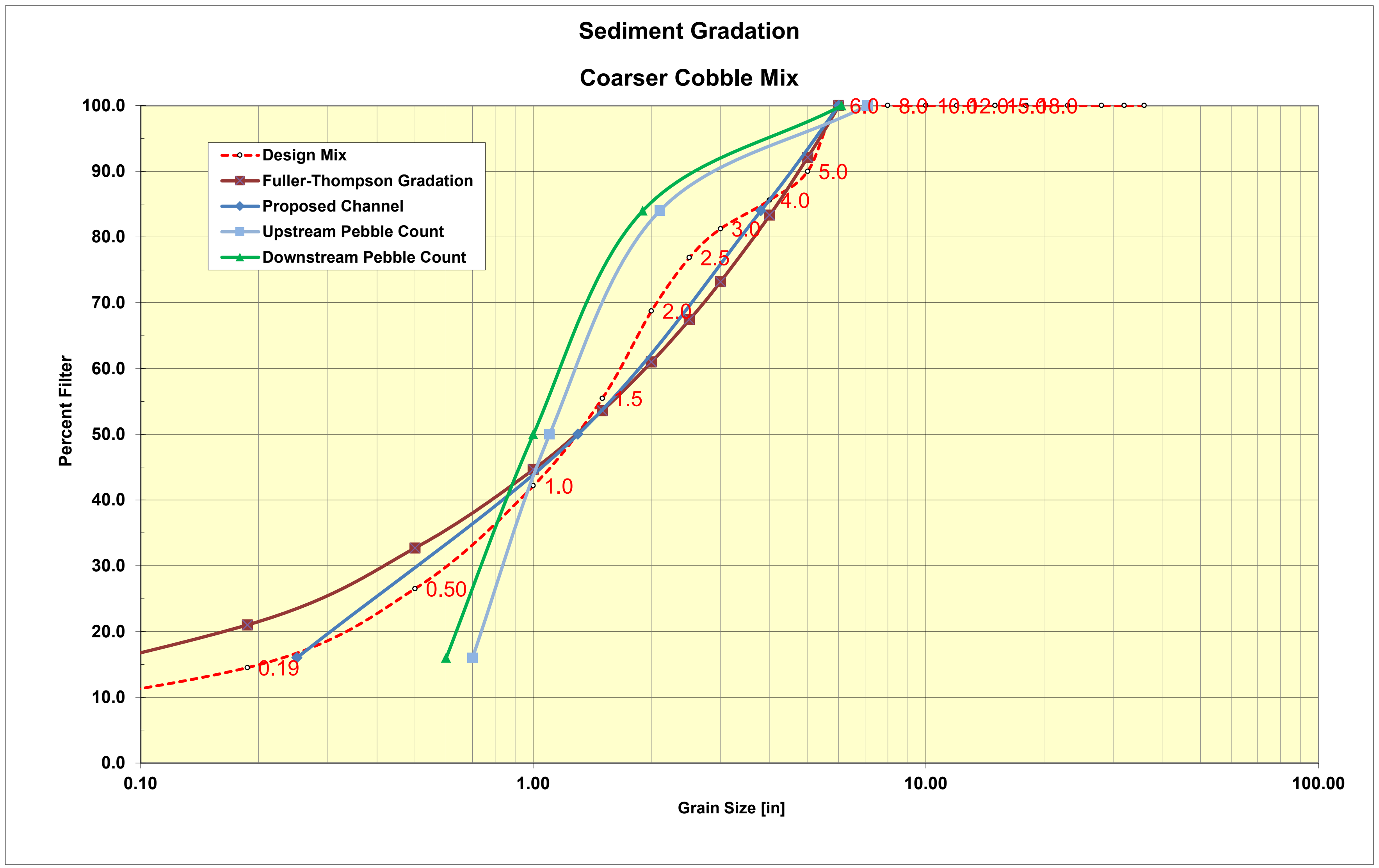
Sand/gravel streams with high relative submergence

γ_s	165	specific weight of sediment particle (lb/ft^3)
γ	62.4	specific weight of water (1b/ft^3)
τ_{D50}	0.05	dimensionless Shields parameter for D50, use table E.1 of USFS manual
		or assume 0.045 for poorly sorted channel bed

Flow	2-Year	100-Year	2080 100-Year	500-Year		
Average Modeled Shear Stress (lb/ft^2)	1.2	1.5	2.2	1.9		
τ_{ci}						
1.51	No Motion	No Motion	Motion	Motion	No Motion	No Motion
1.45	No Motion	Motion	Motion	Motion	No Motion	No Motion
1.40	No Motion	Motion	Motion	Motion	No Motion	No Motion
1.32	No Motion	Motion	Motion	Motion	No Motion	No Motion
1.22	No Motion	Motion	Motion	Motion	No Motion	No Motion
1.16	Motion	Motion	Motion	Motion	No Motion	No Motion
1.08	Motion	Motion	Motion	Motion	No Motion	No Motion
1.02	Motion	Motion	Motion	Motion	No Motion	No Motion
0.96	Motion	Motion	Motion	Motion	No Motion	No Motion
0.88	Motion	Motion	Motion	Motion	No Motion	No Motion
0.83	Motion	Motion	Motion	Motion	No Motion	No Motion
0.78	Motion	Motion	Motion	Motion	No Motion	No Motion
0.71	Motion	Motion	Motion	Motion	No Motion	No Motion
0.68	Motion	Motion	Motion	Motion	No Motion	No Motion
0.63	Motion	Motion	Motion	Motion	No Motion	No Motion
0.58	Motion	Motion	Motion	Motion	No Motion	No Motion
0.51	Motion	Motion	Motion	Motion	No Motion	No Motion
0.42	Motion	Motion	Motion	Motion	No Motion	No Motion

D50	1.30	in
	0.11	ft
	33.0	mm

Otto Gershon, gershoo@wsdot.wa.gov ; 9/2007
modified by Kevin Lautz, P.E. 6/2010



Fuller-Thompson Gradation

Dmax = 6

D[in]	
12.000	136.60
10.000	125.84
8.000	113.82
6.000	100.00
5.000	92.12
4.000	83.32
3.000	73.20
2.500	67.44
2.000	61.00
1.500	53.59
1.000	44.65
0.500	32.69
0.187	21.00
0.017	7.09
0.003	3.25

Otto Gershon, gershoo@wsdot.wa.gov ; 9/2007
modified by Kevin Lautz, P.E. 6/2010

Summary - Stream Simulation Bed Material Design

Project:	Grays Harbor - Wildcat Creek
By:	Karen Comings, P.E.

Design Gradation:

Location:	Proposed Abutment Slope			
	D_{100}	D_{84}	D_{50}	D_{16}
ft	0.83	0.65	0.22	0.04
in	10.00	7.77	2.62	0.51
mm	254	197	66.5	13.0

Design Gradation:

Location:				
	D_{100}	D_{84}	D_{50}	D_{16}
ft				
in				
mm				

Design Gradation:

Location:				
	D_{100}	D_{84}	D_{50}	D_{16}
ft				
in				
mm				

Design Gradation:

Location:				
	D_{100}	D_{84}	D_{50}	D_{16}
ft				
in				
mm				

Determining Aggregate Proportions

Per WSDOT Standard Specifications 9-03.11

Rock Size [in]	Rock Size [mm]	Streambed Sediment	Streambed Cobbles 4"	6"	8"	10"	12"	Streambed Boulders 12"-18"	18"-28"	28"-36"	D_{size}
36.0	914									100	100.0
32.0	813									50	100.0
28.0	711								100		100.0
23.0	584								50		100.0
18.0	457							100			100.0
15.0	381							50			100.0
12.0	305						100				100.0
10.0	254					100	80				100.0
8.0	203				100	80	68				85.0
6.0	152			100	80	68	57				76.3
5.0	127			80	68	57	45				67.5
4.0	102		100	71	57	45	39				58.8
3.0	76.2		80	63	45	38	34				53.8
2.5	63.5	100	65	54	37	32	28				48.8
2.0	50.8	92.5	50	45	29	25	22				41.9
1.5	38.1	79	35	32	21	18	16				33.6
1.0	25.4	66	20	18	13	12	11				25.3
0.50	12.7	48	5	5	5	5	5				15.8
0.19	4.75	29									7.3
0.02	0.425	10									2.5
0.003	0.0750	5									1.3
% per category		25	0	0	0	75	0	0	0	0	--> 100%
% Cobble & Sediment		25.0	0.0	0.0	0.0	75.0	0.0	0.0	0.0	0.0	100.0%

Streambed Mobility/Stability Analysis

Modified Shields Approach

References:

Stream Simulation: An Ecological Approach to Providing Passage for Aquatic Organizms at Road-Stream Crossings

Appendix E--Methods for Streambed Mobility/Stability Analysis

Limitations:

D_{84} must be between 0.40 in and 10 in

uniform bed material (Di < 20-30 times D50)

Slopes less than 5%

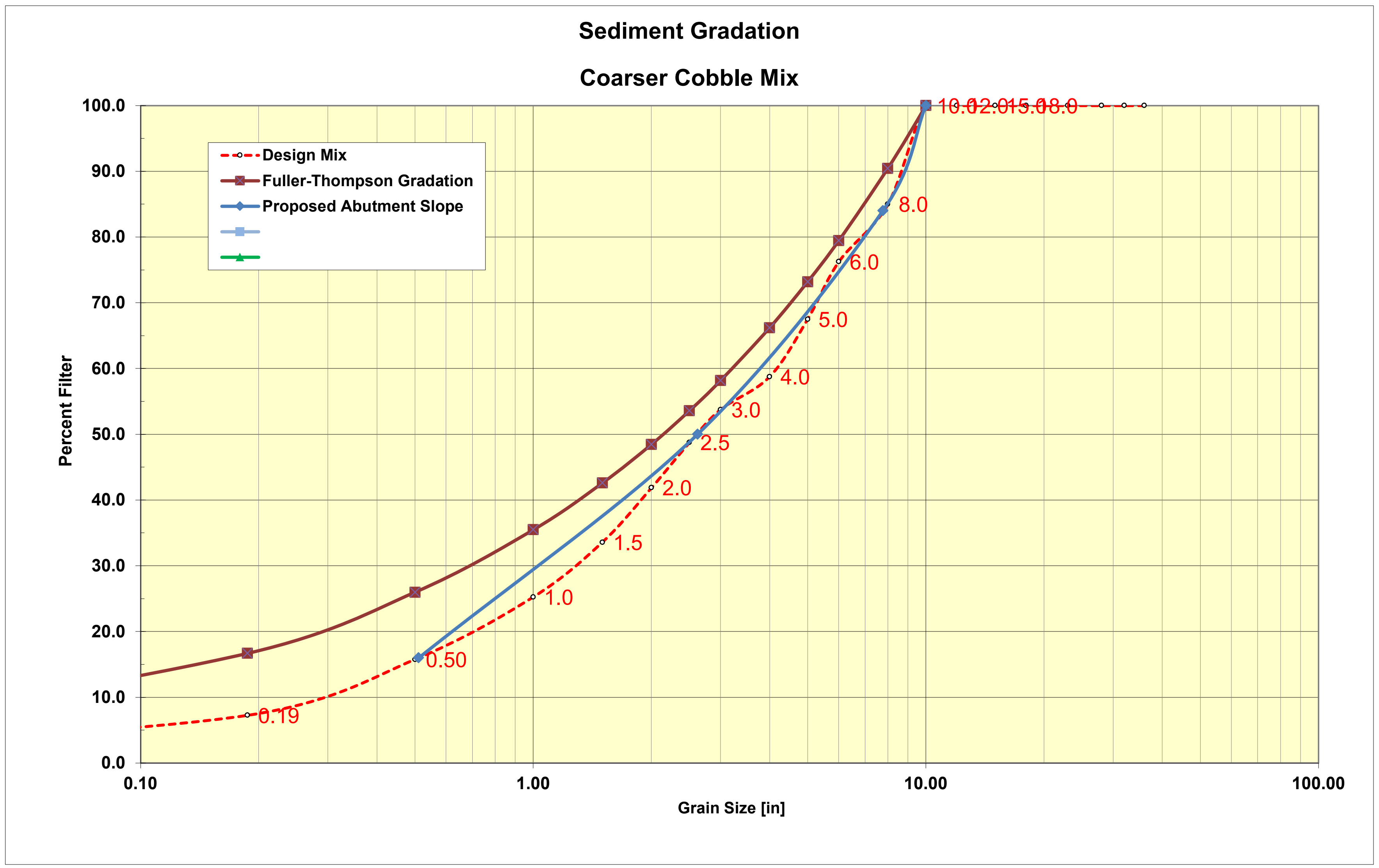
Sand/gravel streams with high relative submergence

γ_s	165	specific weight of sediment particle (lb/ft^3)
γ	62.4	specific weight of water (1b/ft^3)
τ_{D50}	0.052	dimensionless Shields parameter for D50, use table E.1 of USFS manual
		or assume 0.045 for poorly sorted channel bed

Flow	2-Year	100-Year	2080 100-Year	500-Year		
Average Modeled Shear Stress (lb/ft^2)	1.2	1.5	2.2	1.9		
τ_{ci}						
2.56	No Motion	No Motion	No Motion	No Motion	No Motion	No Motion
2.47	No Motion	No Motion	No Motion	No Motion	No Motion	No Motion
2.37	No Motion	No Motion	No Motion	No Motion	No Motion	No Motion
2.24	No Motion	No Motion	No Motion	No Motion	No Motion	No Motion
2.08	No Motion	No Motion	Motion	No Motion	No Motion	No Motion
1.97	No Motion	No Motion	Motion	No Motion	No Motion	No Motion
1.84	No Motion	No Motion	Motion	Motion	No Motion	No Motion
1.74	No Motion	No Motion	Motion	Motion	No Motion	No Motion
1.63	No Motion	No Motion	Motion	Motion	No Motion	No Motion
1.49	No Motion	Motion	Motion	Motion	No Motion	No Motion
1.41	No Motion	Motion	Motion	Motion	No Motion	No Motion
1.32	No Motion	Motion	Motion	Motion	No Motion	No Motion
1.21	No Motion	Motion	Motion	Motion	No Motion	No Motion
1.15	Motion	Motion	Motion	Motion	No Motion	No Motion
1.07	Motion	Motion	Motion	Motion	No Motion	No Motion
0.99	Motion	Motion	Motion	Motion	No Motion	No Motion
0.87	Motion	Motion	Motion	Motion	No Motion	No Motion
0.71	Motion	Motion	Motion	Motion	No Motion	No Motion

D50	2.62	in
	0.22	ft
	66.5	mm

Otto Gershon, gershoo@wsdot.wa.gov ; 9/2007
modified by Kevin Lautz, P.E. 6/2010

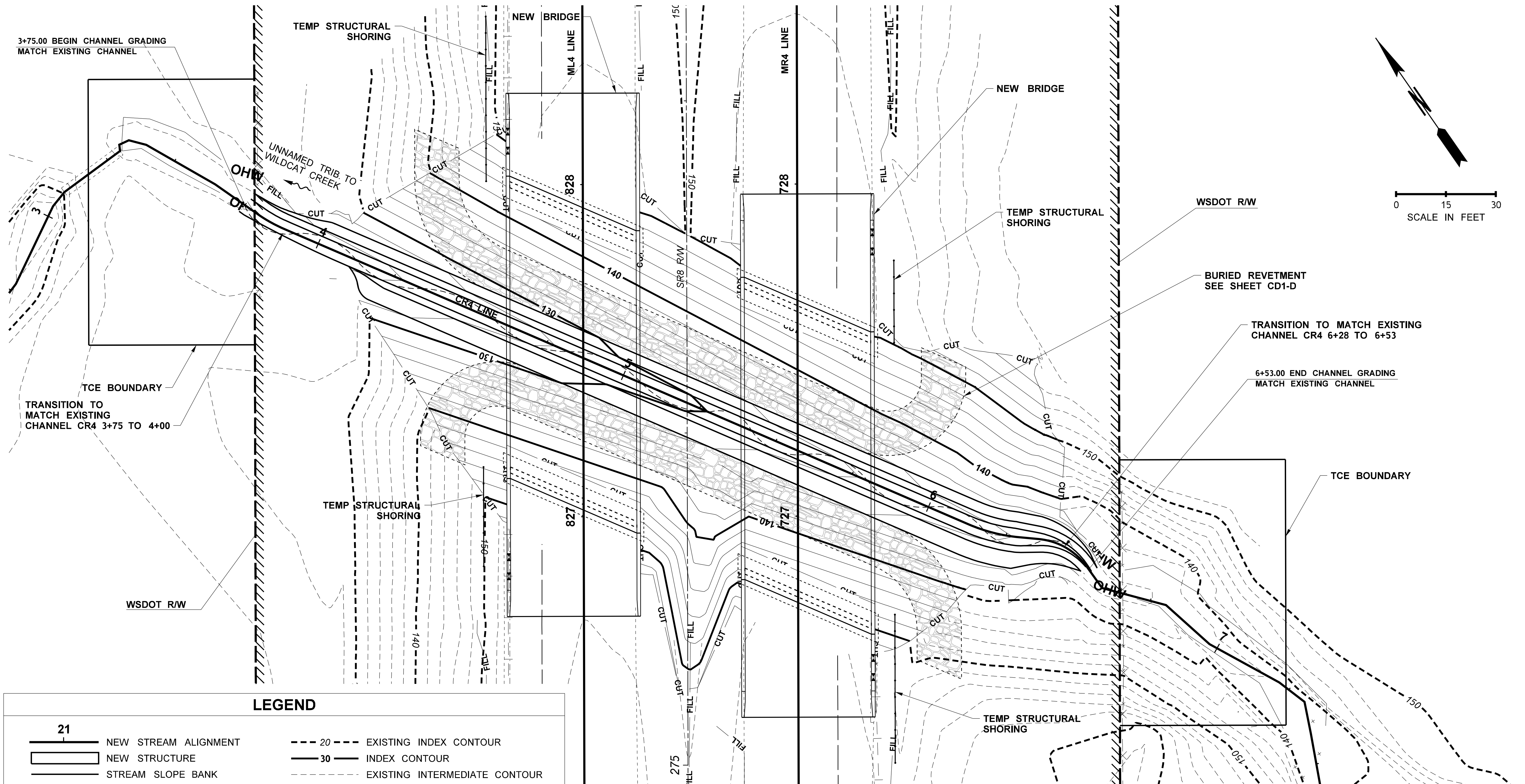


Fuller-Thompson Gradation

Dmax =	**10**
D[in]	
12.000	108.55
10.000	100.00
8.000	90.45
6.000	79.46
5.000	73.20
4.000	66.21
3.000	58.17
2.500	53.59
2.000	48.47
1.500	42.58
1.000	35.48
0.500	25.97
0.187	16.69
0.017	5.63
0.003	2.58

Otto Gershon, gershoo@wsdot.wa.gov ; 9/2007
modified by Kevin Lautz, P.E. 6/2010

Appendix D: Stream Plan Sheets, Profile, Details



LEGEND

- 21 — NEW STREAM ALIGNMENT
- NEW STRUCTURE
- STREAM SLOPE BANK
- OHW — ORDINARY HIGH WATER
- CUT — FILL — LIMITS OF EARTHWORK
- 286 — HIGHWAY ALIGNMENT
- WSDOT RIGHT OF WAY
- EASEMENT LINE
- 20 — EXISTING INDEX CONTOUR
- 30 — INDEX CONTOUR
- EXISTING INTERMEDIATE CONTOUR
- INTERMEDIATE CONTOUR
- EDGE OF PAVEMENT
- EXISTING DITCH
- TEMP STRUCTURAL SHORING
- WB — WETLAND

SR 8 MP 3.16 UNNAMED TRIBUTARY TO WILDCAT CREEK

FILE NAME	c:\users\rhw\pw_wsdot\d0331511\SR8MP3.16_A_PS_CR_001.dgn
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DATE	10/13/2022
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DESIGNED BY	K. COMINGS
ENTERED BY	R. WILCOX
CHECKED BY	J. GAGE
PROJ. ENGR.	B. ELLIOTT
REGIONAL ADM.	S. ROARK

REVISION | DATE | BY

REGION NO. 10 | STATE WASH | FED.AID PROJ.NO. ARPA001

JOB NUMBER 21C522

CONTRACT NO. XL6115 | LOCATION NO.

P.E. STAMP BOX | DATE

P.E. STAMP BOX | DATE

Washington State Department of Transportation

DAVID EVANS AND ASSOCIATES INC.

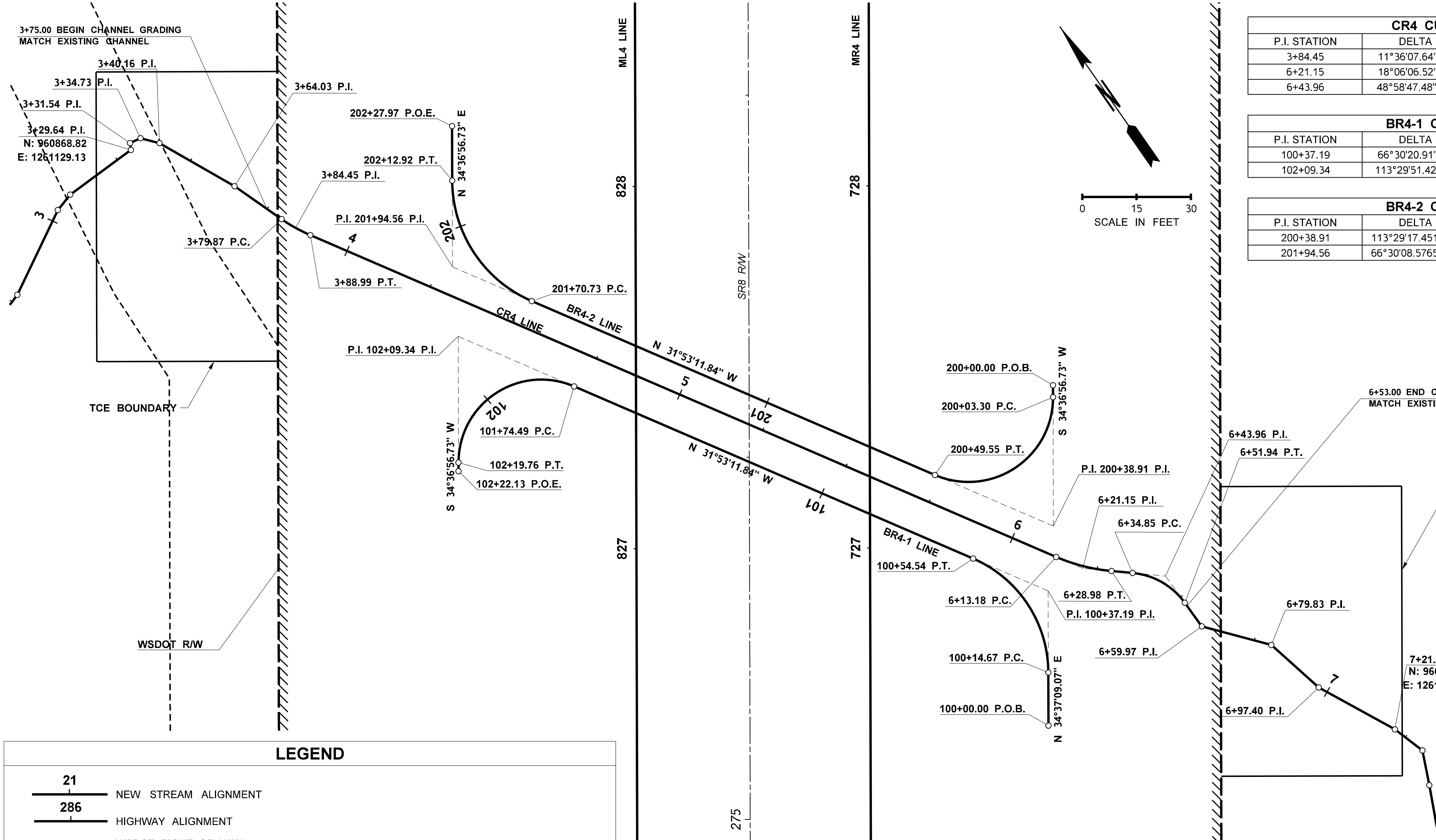
US 12 AND SR 8
GRAYS HARBOR COUNTY
REMOVE FISH BARRIERS

STREAM PLAN

PLAN REF NO **CR1-D**

SHEET OF SHEETS

pw:\\HQOLYMAPPW03P.WSDOT.LOC:WSDOT\Documents_HQ\Fish Passage\ORproj\008\3.16_TribToWildcatCr\Design_CAD_Sheets\Preliminary Design\SR8MP3.16_A_PS_CR_001.dgn



CR4 CURVE DATA				
P.I. STATION	DELTA	RADIUS	TANGENT	LENGTH
3+84.45	11°36'07.64" LT	45.00	4.57	9.11
6+21.15	18°06'06.52" LT	50.00	7.97	15.80
6+43.96	48°58'47.48" RT	20.00	9.11	17.10

BR4-1 CURVE DATA				
P.I. STATION	DELTA	RADIUS	TANGENT	LENGTH
100+37.19	66°30'20.91" LT	34.35	22.52	39.87
102+09.34	113°29'51.42" LT	22.85	34.85	45.26

BR4-2 CURVE DATA				
P.I. STATION	DELTA	RADIUS	TANGENT	LENGTH
200+38.91	113°29'17.451" RT	23.35	35.61	46.23
201+94.56	66°30'08.5765" RT	36.35	23.83	42.19

LEGEND

21 — NEW STREAM ALIGNMENT

286 — HIGHWAY ALIGNMENT

WSDOT RIGHT OF WAY

EASEMENT LINE

SR 8 MP 3.16 UNNAMED TRIBUTARY TO WILDCAT CREEK

FILE NAME	c:\users\rhw\pw_wsdot\d0331511\SR8MP3.16_A_PS_CR_002.dgn				
TIME	5:52:53 PM				
DATE	10/13/2022				
PLOTTED BY	Rhw				
DESIGNED BY	K. COMINGS				
ENTERED BY	R. WILCOX				
CHECKED BY	J. GAGE				
PROJ. ENGR.	B. ELLIOTT				
REGIONAL ADM.	S. ROARK	REVISION	DATE	BY	

REGION NO. 10 | STATE WASH | FED.AID PROJ.NO. ARPA001

JOB NUMBER 21C522

CONTRACT NO. XL6115 | LOCATION NO.

P.E. STAMP BOX DATE

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Washington State Department of Transportation

DAVID EVANS AND ASSOCIATES INC.

US 12 AND SR 8
GRAYS HARBOR COUNTY
REMOVE FISH BARRIERS

STREAM PLAN

PLAN REF NO CR2-D

SHEET OF SHEETS

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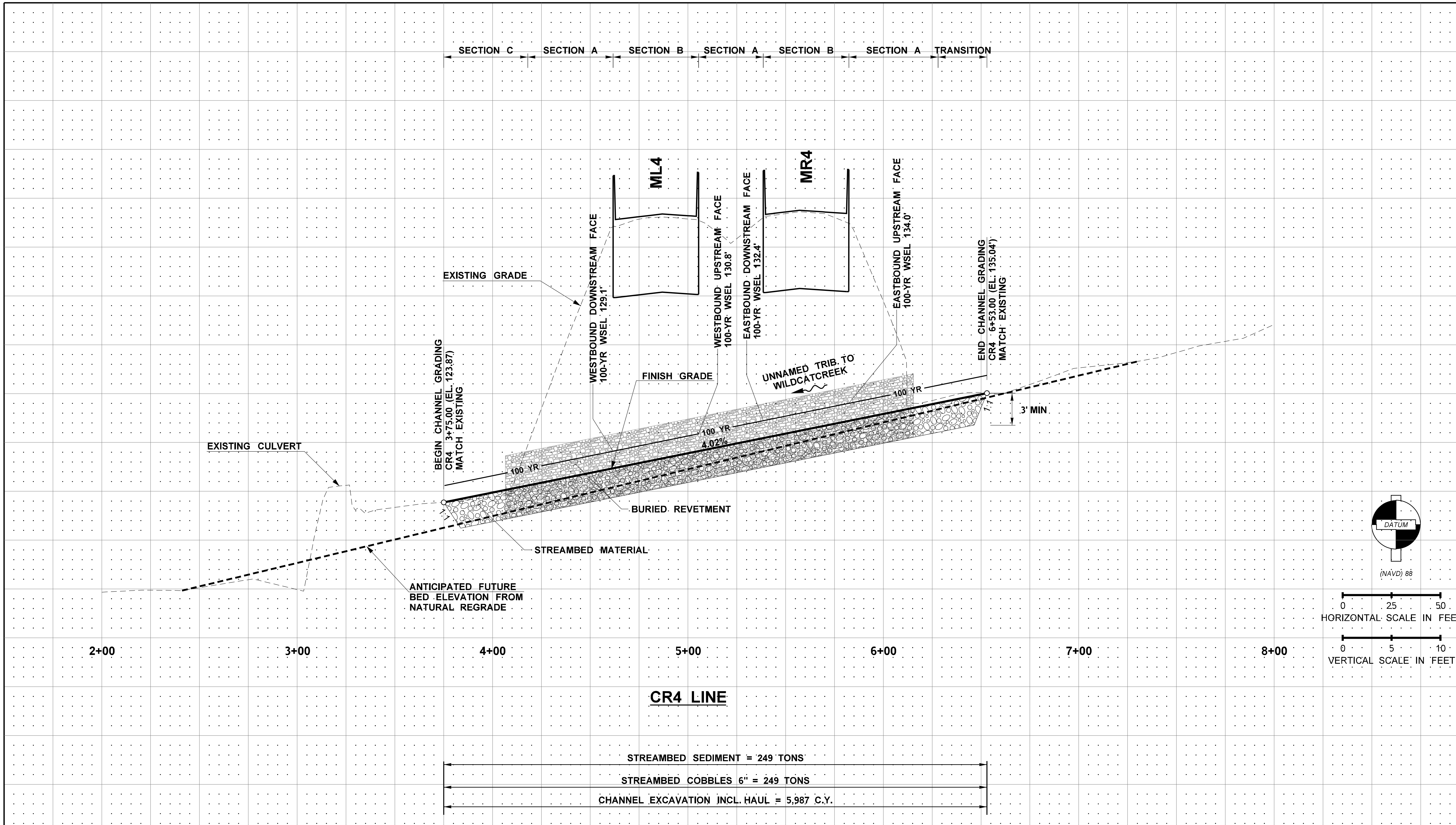

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PROJ. ENGR.	B. ELLIOTT				
REGIONAL ADM.	S. ROARK	REVISION	DATE	BY	

REGION NO.	STATE	FED.AID PROJ.NO.
10	WASH	ARPA001
JOB NUMBER 21C522		
CONTRACT NO. XL6115		LOCATION NO.

P.E. STAMP BOX DATE

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Washington State Department of Transportation

DAVID EVANS AND ASSOCIATES INC.

US 12 AND SR 8
GRAYS HARBOR COUNTY
REMOVE FISH BARRIERS

STREAM PROFILE

PLAN REF. NO. CP1-D

SHEET OF SHEETS

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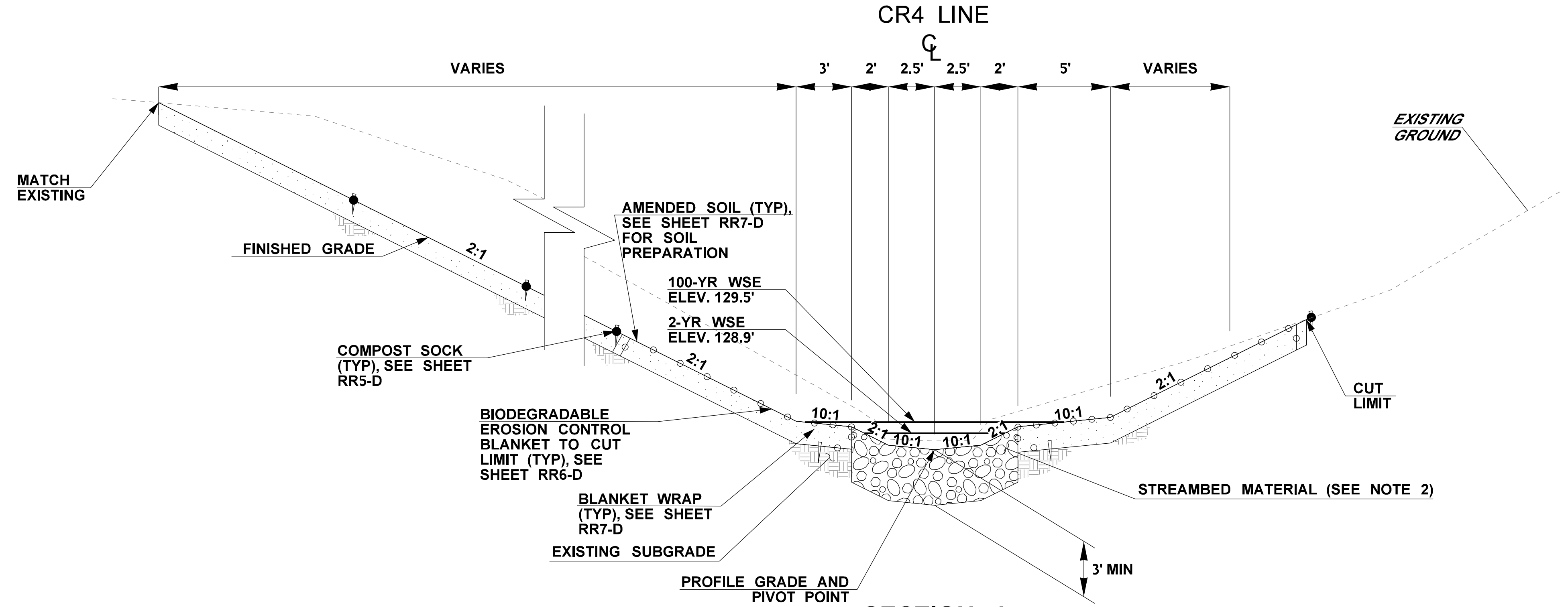
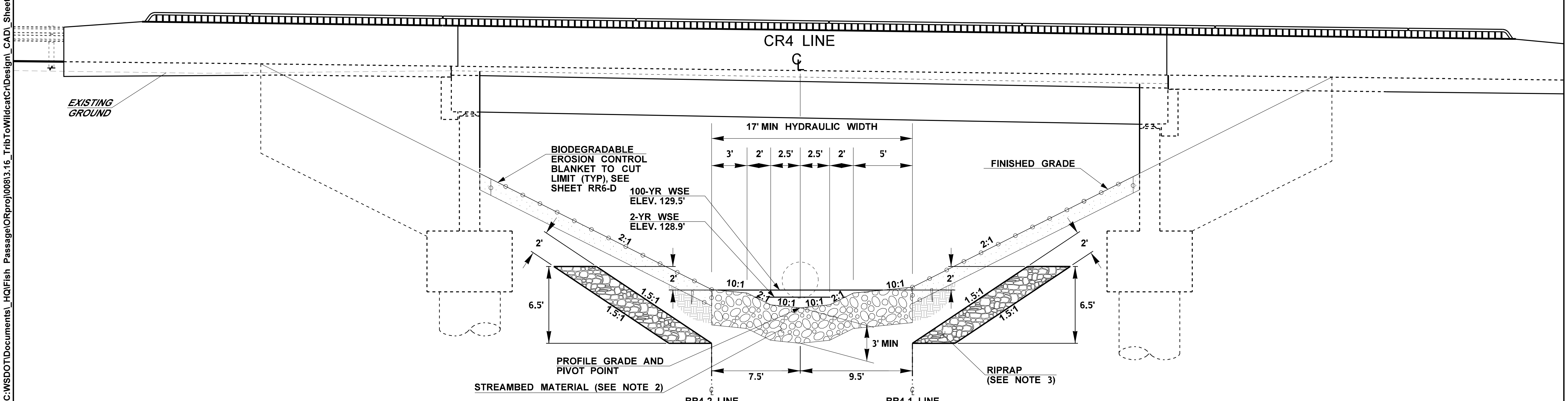


SECTION A

CR4 4+18.00 TO CR4 4+61.67
CR4 5+05.47 TO CR4 5+38.56
CR4 5+82.35 TO CR4 6+28.00

NOTES:

1. CREEK AND BRIDGE STRUCTURE AT A SKEW. SEE STREAM PLAN (SHEET CR1-D) FOR ADDITIONAL INFORMATION.
2. STREAMBED MATERIAL SHALL CONSIST OF A WELL GRADED MIX OF 50 PERCENT 6" STREAMBED COBBLES (9-03.11(2)) AND 50 PERCENT STREAMBED SEDIMENT (9-03.11(1)).
3. RIPRAP SHALL BE ROCK FOR EROSION AND SCOUR PROTECTION CLASS A (9-13.4(2)). THE BOTTOM OF THE BURIED REVETMENTS SHALL BE AT AN ELEVATION EQUAL TO THE BOTTOM OF THE STREAMBED MATERIAL. BURIED REVETMENTS WRAP AROUND BRIDGE ABUTMENTS AS SHOWN ON SHEET CR1-D.



SECTION B

CR4 4+61.67 TO CR4 5+05.47
CR4 5+38.56 TO CR4 5+82.35

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SR 8 MP 3.16 UNNAMED TRIBUTARY TO WILDCAT CREEK

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DESIGNED BY	K. COMINGS				
ENTERED BY	R. WILCOX				
CHECKED BY	J. GAGE				
PROJ. ENGR.	B. ELLIOTT				
REGIONAL ADM.	S. ROARK	REVISION	DATE	BY	

REGION NO. 10 | STATE WASH | FED.AID PROJ.NO. ARPA001
JOB NUMBER 21C522
CONTRACT NO. XL6115 | LOCATION NO.

P.E. STAMP BOX DATE
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Washington State Department of Transportation
DAVID EVANS AND ASSOCIATES INC.

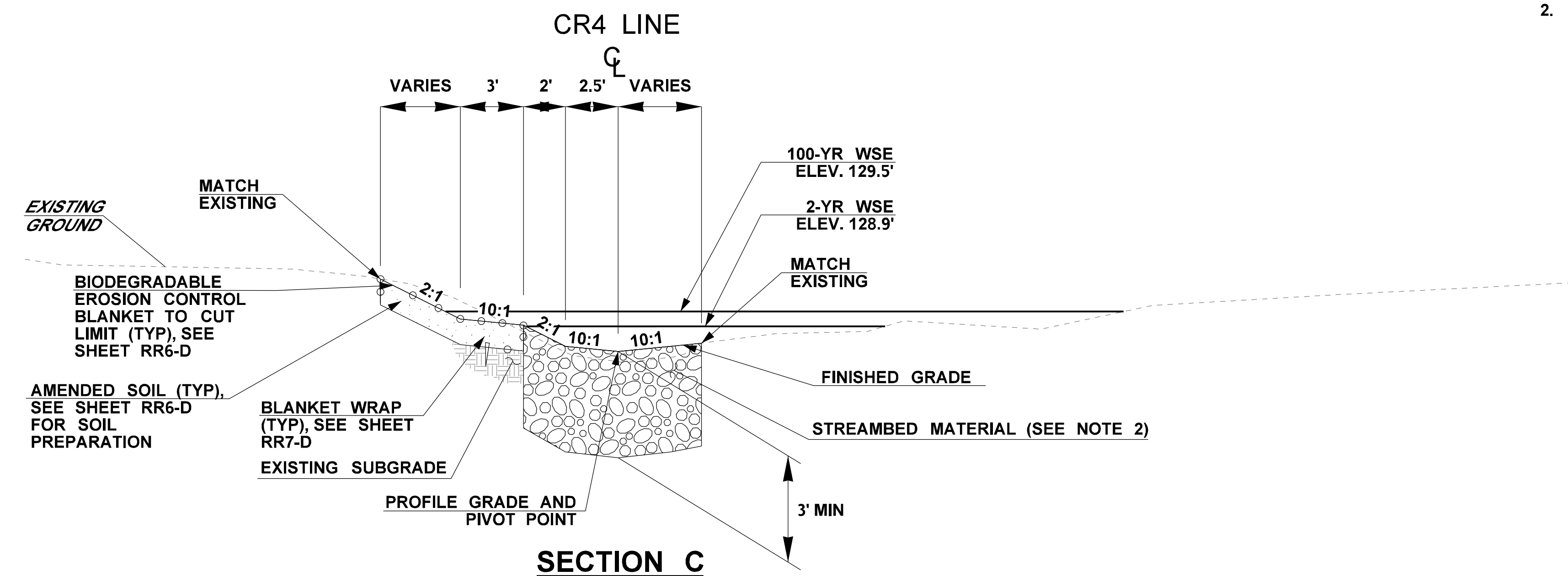
US 12 AND SR 8
GRAYS HARBOR COUNTY
REMOVE FISH BARRIERS

STREAM DETAILS

PLAN REF NO CD1-D
SHEET OF SHEETS

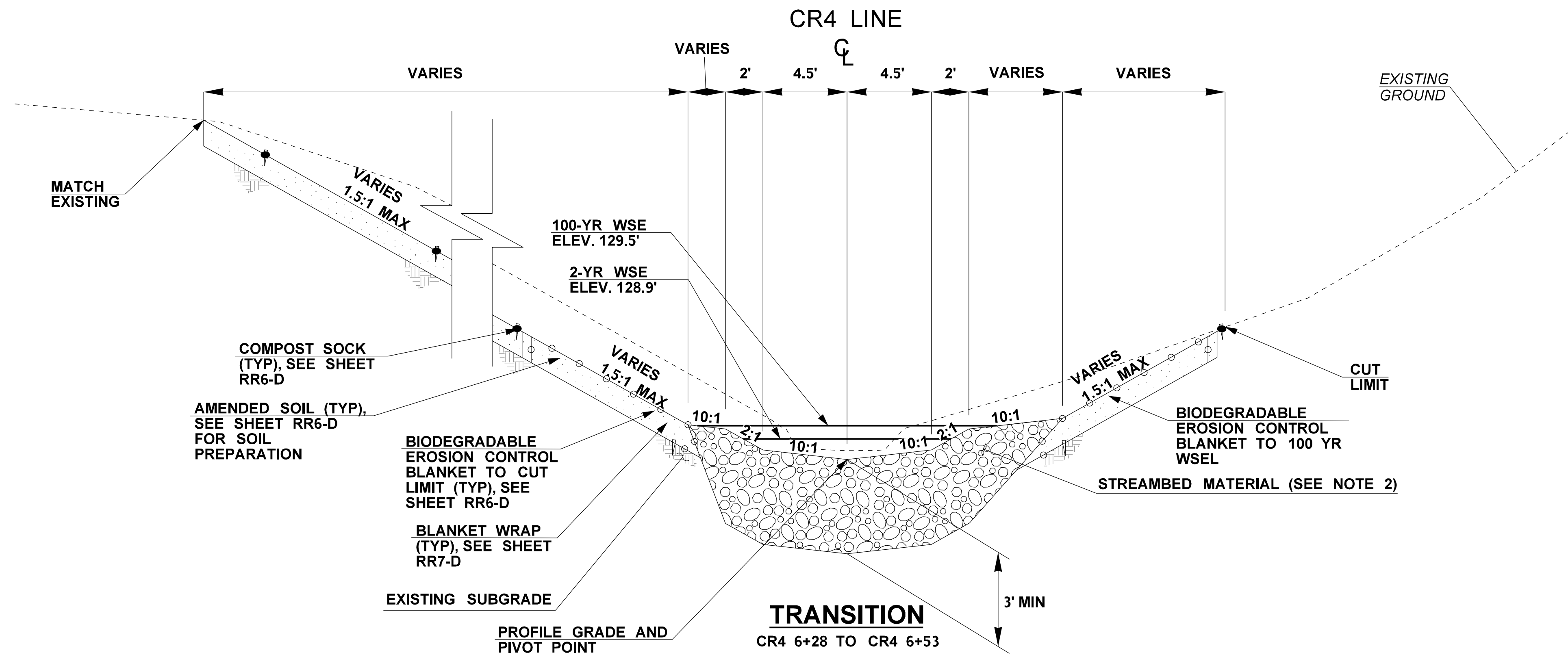
NOTES:

1. CREEK AND BRIDGE STRUCTURE AT A SKEW. SEE STREAM PLAN FOR ADDITIONAL INFORMATION.
2. STREAMBED MATERIAL SHALL CONSIST OF A WELL GRADED MIX OF 50 PRECENT 6" STREAMBED COBBLES (9-03.11(2)) AND 50 PRECENT STREAMBED SEDIMENT (9-03.11(1))



SECTION C

CR4 3+75 TO CR4 4+18



TRANSITION

CR4 6+28 TO CR4 6+53

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PROJ. ENGR.	B. ELLIOTT			
REGIONAL ADM.	S. ROARK	REVISION	DATE	BY

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JOB NUMBER 21C522

CONTRACT NO. XL6115 | LOCATION NO.

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Washington State Department of Transportation

DAVID EVANS AND ASSOCIATES INC.

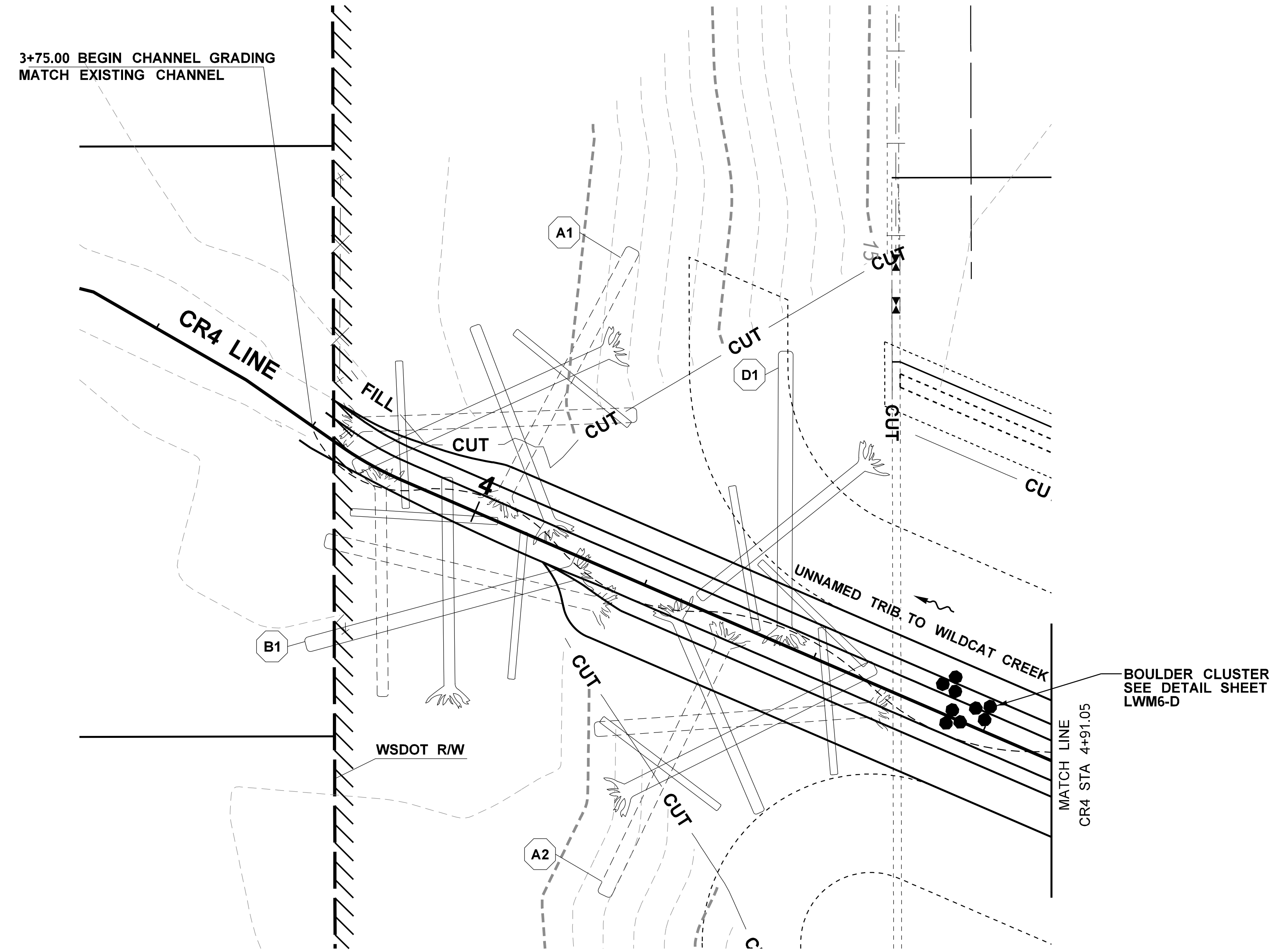
SR 8 MP 3.16 UNNAMED TRIBUTARY TO WILDCAT CREEK

US 12 AND SR 8
GRAYS HARBOR COUNTY
REMOVE FISH BARRIERS

STREAM DETAILS

PLAN REF NO CD2-D

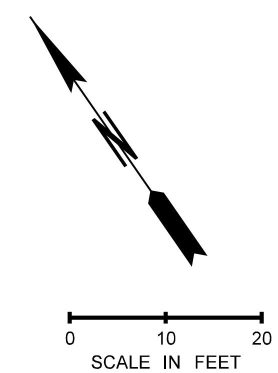
SHEET OF SHEETS



LARGE WOODY MATERIAL - DOWNSTREAM END

LEGEND

21	NEW STREAM ALIGNMENT	20	EXISTING INDEX CONTOUR
	NEW BRIDGE	30	INDEX CONTOUR
	STREAM SLOPE BANK		EXISTING INTERMEDIATE CONTOUR
OHW	ORDINARY HIGH WATER		INTERMEDIATE CONTOUR
CUT — FILL	LIMITS OF EARTHWORK		EDGE OF PAVEMENT
286	HIGHWAY ALIGNMENT		
	WSDOT RIGHT OF WAY		
	EASEMENT LINE		



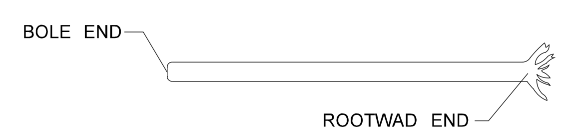
LEGEND

- 24" MIN DIA. 40' MIN. LENGTH, WITH ROOTWAD (9 TOTAL)
- 18" MIN DIA. 30' MIN. LENGTH, WITH ROOTWAD (5 TOTAL)
- 12" MIN DIA. 20' MIN. LENGTH, WITHOUT ROOTWAD (8 TOTAL)
- CLUSTER ID, SEE SHEETS LWM3-D, LWM4-D, AND LWM5-D (x)

		BOLE		ROOTWAD		
CLUSTER ID	LOG ID	STATION	OFFSET	STATION	OFFSET	NOTES
B1	1	3+94.8	2.8' LT	4+06.4	23.4' RT	SEE SHEET LWM4-D
B1	2	3+87.2	25.9' RT	4+15.9	2.0' RT	SEE SHEET LWM4-D
B1	3	3+98.5	27.9' RT	3+86.9	1.5' RT	SEE SHEET LWM4-D
B1	4	3+84.2	11.8' RT	4+20.0	4.8' RT	SEE SHEET LWM4-D
B1	5	3+85.1	6.9' RT	4+03.3	0.1' LT	SEE SHEET LWM4-D
B1	6	4+13.5	18.8' RT	4+07.3	0.1' LT	SEE SHEET LWM4-D
A1	1	3+89.9	23.1' LT	4+10.0	2.4' LT	SEE SHEET LWM3-D
A1	2	3+82.8	1.5' RT	4+07.8	27.2' LT	SEE SHEET LWM3-D
A1	3	4+05.6	41.2' LT	4+02.6	3.1' LT	SEE SHEET LWM3-D
A1	4	4+15.0	20.7' LT	3+80.0	3.7' LT	SEE SHEET LWM3-D
A1	5	3+95.2	24.6' LT	4+14.4	18.9' LT	SEE SHEET LWM3-D
A1	6	3+79.5	14.0' LT	3+91.2	3.5' RT	SEE SHEET LWM3-D
A2	1	4+51.7	22.1' RT	4+30.9	2.3' RT	SEE SHEET LWM3-D
A2	2	4+58.0	2.3' LT	4+34.1	26.6' RT	SEE SHEET LWM3-D
A2	3	4+36.4	40.6' RT	4+38.1	2.9' RT	SEE SHEET LWM3-D
A2	4	4+26.5	20.8' RT	4+60.2	3.1' RT	SEE SHEET LWM3-D
A2	5	4+46.3	23.8' RT	4+26.9	19.0' RT	SEE SHEET LWM3-D
A2	6	4+58.7	13.3' RT	4+49.3	4.2' LT	SEE SHEET LWM3-D
D1	1	4+29.9	36.8' LT	4+45.1	2.0' LT	SEE SHEET LWM5-D
D1	2	4+32.4	1.3' LT	4+46.3	27.0' LT	SEE SHEET LWM5-D
D1	3	4+30.6	17.1' LT	4+41.6	0.3' LT	SEE SHEET LWM5-D
D1	4	4+38.0	9.1' LT	4+56.9	1.8' LT	SEE SHEET LWM5-D

NOTES

1. DASHED LINES INDICATE BURIED LOGS.
2. SEE SHEETS LWM3-D, LWM4-D, AND LWM5-D FOR LOG ID NUMBERS.
3. LOCATIONS AND ORIENTATIONS OF LARGE WOODY MATERIAL (LWM) STRUCTURES AS SHOWN ON THIS SHEET ARE APPROXIMATE AND WILL BE DIRECTED BY THE ENGINEER IN THE FIELD. SEE SPECIAL PROVISION "LARGE WOODY MATERIAL (LWM) STRUCTURES".
4. BURIED LOGS SHALL NOT CONTACT THE BURIED REVETMENT.
5. 100-YR WSEL: 133.37'



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DATE	10/13/2022
PLOTTED BY	Rhw
DESIGNED BY	K. COMINGS
ENTERED BY	R. WILCOX
CHECKED BY	J. GAGE
PROJ. ENGR.	B. ELLIOTT
REGIONAL ADM.	S. ROARK

REVISION | DATE | BY

REGION NO. 10 | STATE WASH | FED.AID PROJ.NO. ARPA001

JOB NUMBER 21C522

CONTRACT NO. XL6115 | LOCATION NO.

P.E. STAMP BOX DATE

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Washington State Department of Transportation

DAVID EVANS AND ASSOCIATES INC.

SR 8 MP 3.16 UNNAMED TRIBUTARY TO WILDCAT CREEK

US 12 AND SR 8
GRAYS HARBOR COUNTY
REMOVE FISH BARRIERS

LARGE WOODY MATERIAL PLAN

PLAN REF NO LWM1-D

SHEET OF SHEETS

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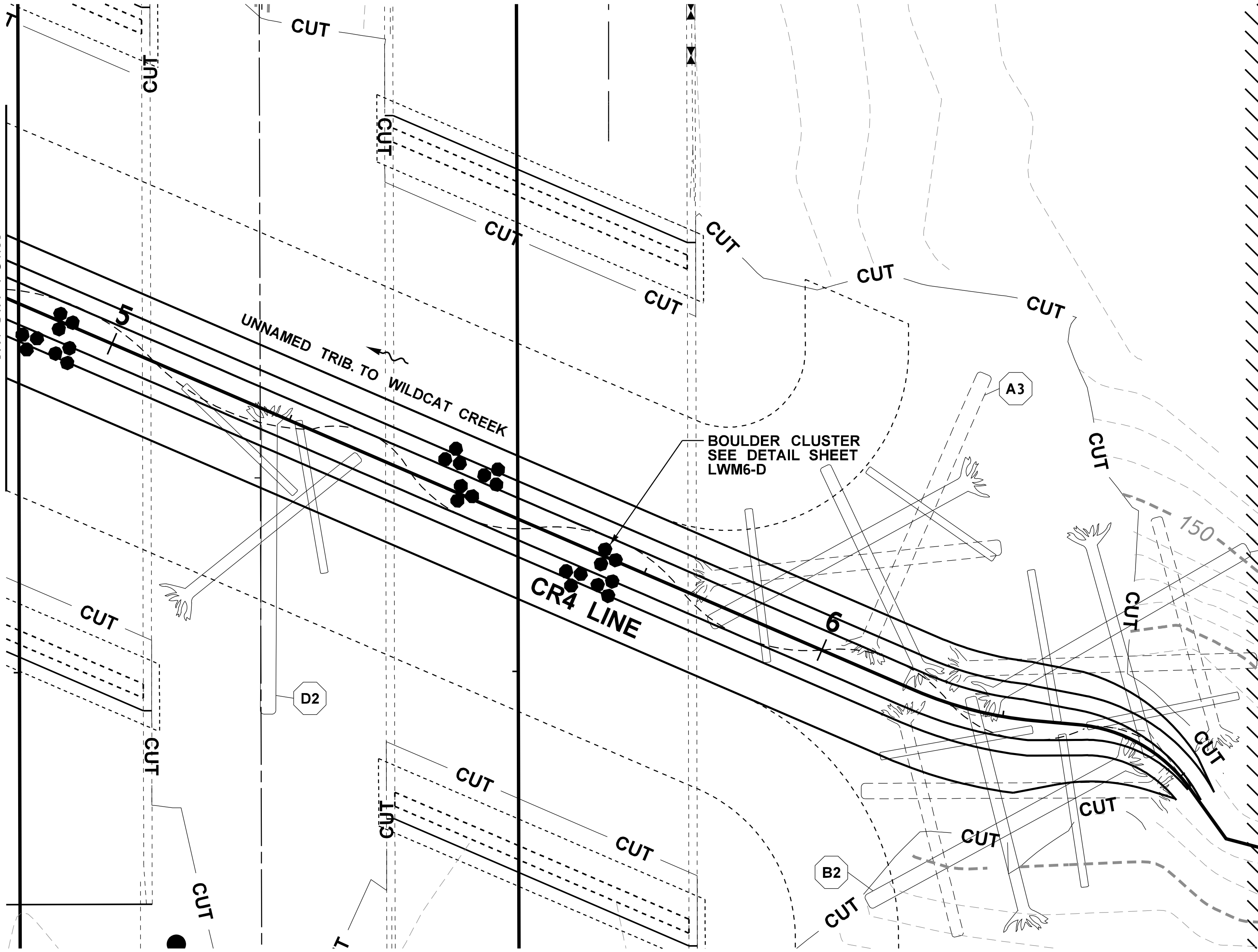
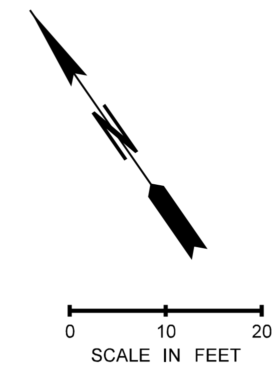


LARGE WOODY MATERIAL - UPSTREAM END

LEGEND

NEW STREAM ALIGNMENT	EXISTING INDEX CONTOUR
NEW BRIDGE	INDEX CONTOUR
STREAM SLOPE BANK	EXISTING INTERMEDIATE CONTOUR
ORDINARY HIGH WATER	INTERMEDIATE CONTOUR
LIMITS OF EARTHWORK	EDGE OF PAVEMENT
HIGHWAY ALIGNMENT	
WSDOT RIGHT OF WAY	



LEGEND

24" MIN DIA. 40' MIN. LENGTH, WITH ROOTWAD (8 TOTAL)

18" MIN DIA. 30' MIN. LENGTH, WITH ROOTWAD (6 TOTAL)

12" MIN DIA. 20' MIN. LENGTH, WITHOUT ROOTWAD (8 TOTAL)

CLUSTER ID, SEE SHEETS LWM3-D, LWM4-D, AND LWM5-D

		BOLE		ROOTWAD		
CLUSTER ID	LOG ID	STATION	OFFSET	STATION	OFFSET	NOTES
D1	1	5+37.8	35.9' RT	5+22.9	1.0' RT	SEE SHEET LWM5-C
D1	2	5+35.2	0.6' RT	5+21.5	25.8' RT	SEE SHEET LWM5-C
D1	3	5+36.9	16.4' RT	5+26.1	0.2' LT	SEE SHEET LWM5-C
D1	4	5+29.6	8.25' RT	5+10.6	1.1' RT	SEE SHEET LWM5-C
A3	1	5+90.9	22.0' LT	6+12.5	3.1' LT	SEE SHEET LWM3-C
A3	2	5+85.1	2.4' RT	6+08.7	27.3' LT	SEE SHEET LWM3-C
A3	3	6+05.3	41.1' LT	6+05.2	3.5' LT	SEE SHEET LWM3-C
A3	4	6+18.2	21.3' LT	5+83.0	2.9' LT	SEE SHEET LWM3-C
A3	5	5+96.0	23.9' LT	6+17.9	19.6' LT	SEE SHEET LWM3-C
A3	6	5+84.0	13.0' LT	5+94.1	4.3' RT	SEE SHEET LWM3-C
B2	1	6+20.4	1.7' LT	6+30.2	25.0' RT	SEE SHEET LWM4-C
B2	2	6+16.5	27.8' RT	6+42.4	2.9' RT	SEE SHEET LWM4-C
B2	3	6+24.5	28.9' RT	6+13.4	4.0' RT	SEE SHEET LWM4-C
B2	4	6+11.9	14.6' RT	6+49.2	3.5' RT	SEE SHEET LWM4-C
B2	5	6+12.3	9.5' RT	6+29.0	1.1' RT	SEE SHEET LWM4-C
B2	6	6+54.4	18.6' RT	6+33.0	1.3' RT	SEE SHEET LWM4-C
B3	1	6+45.2	0.8' RT	6+34.4	23.7' LT	SEE SHEET LWM4-C
B3	2	6+43.2	29.1' LT	6+23.7	2.4' LT	SEE SHEET LWM4-C
B3	3	6+38.1	28.4' LT	6+49.3	7.3' LT	SEE SHEET LWM4-C
B3	4	6+47.5	18.0' LT	6+18.7	5.0' LT	SEE SHEET LWM4-C
B3	5	6+48.3	12.8' LT	6+35.9	0.1' RT	SEE SHEET LWM4-C
B3	6	6+25.5	19.4' LT	6+32.1	0.1' LT	SEE SHEET LWM4-C

NOTES

1. DASHED LINES INDICATE BURIED LOGS.
2. SEE SHEETS LWM3-D, LWM4-D, AND LWM5-D FOR LOG ID NUMBERS.
3. LOCATIONS AND ORIENTATIONS OF LARGE WOODY MATERIAL (LWM) STRUCTURES AS SHOWN ON THIS SHEET ARE APPROXIMATE AND WILL BE DIRECTED BY THE ENGINEER IN THE FIELD. SEE SPECIAL PROVISION "LARGE WOODY MATERIAL (LWM) STRUCTURES".
4. BURIED LOGS SHALL NOT CONTACT THE BURIED REVETMENT.
5. 100-YR WSEL: 133.37'

SR 8 MP 3.16 UNNAMED TRIBUTARY TO WILDCAT CREEK

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DESIGNED BY	K. COMINGS
ENTERED BY	R. WILCOX
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PROJ. ENGR.	B. ELLIOTT
REGIONAL ADM.	S. ROARK

REVISION | DATE | BY

REGION NO. 10 | STATE WASH | FED.AID PROJ.NO. ARPA001

JOB NUMBER 21C522

CONTRACT NO. XL6115 | LOCATION NO.

P.E. STAMP BOX DATE

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Washington State Department of Transportation

DAVID EVANS AND ASSOCIATES INC.

US 12 AND SR 8
GRAYS HARBOR COUNTY
REMOVE FISH BARRIERS

LARGE WOODY MATERIAL PLAN

PLAN REF NO LWM2-D

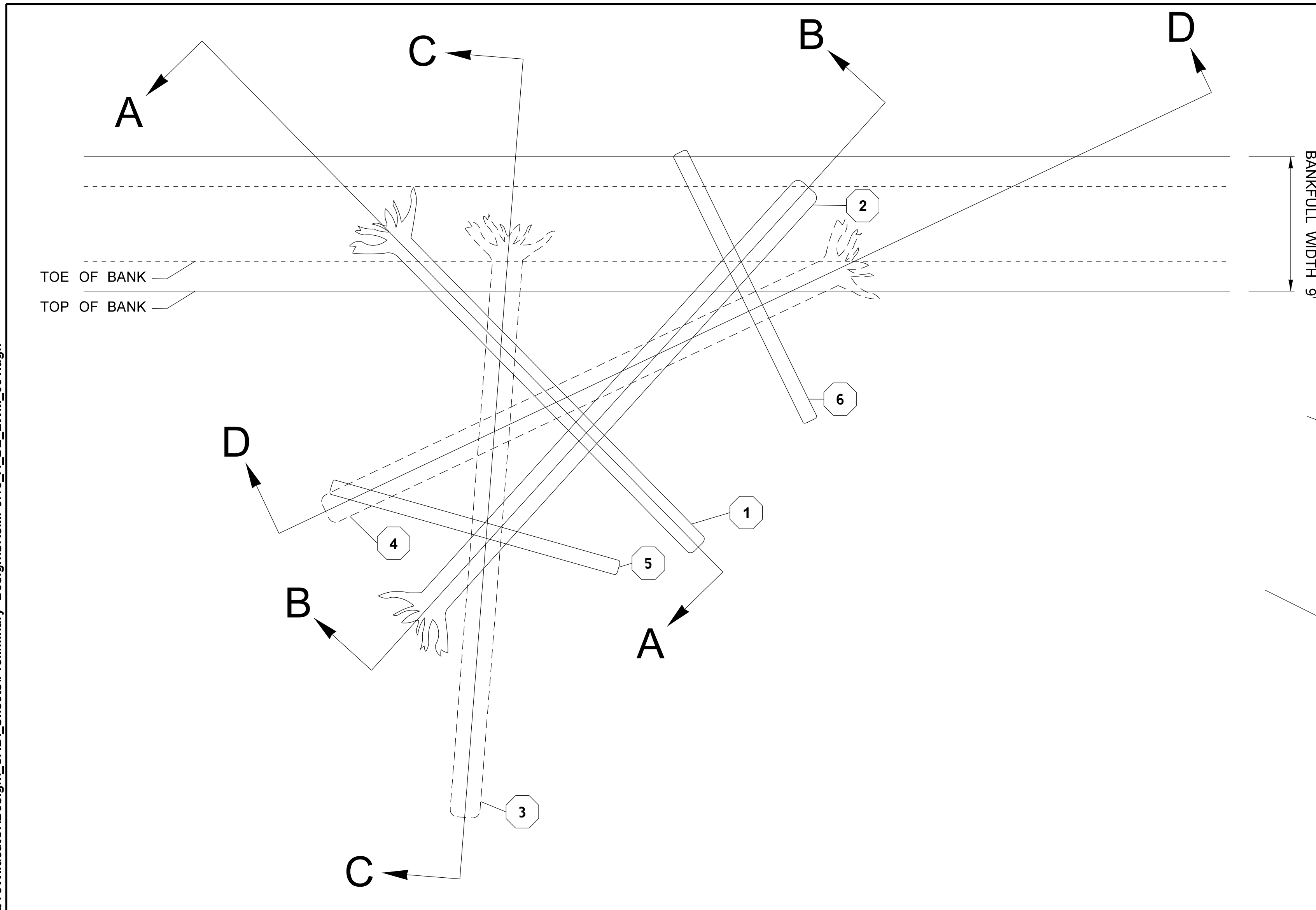
SHEET

OF

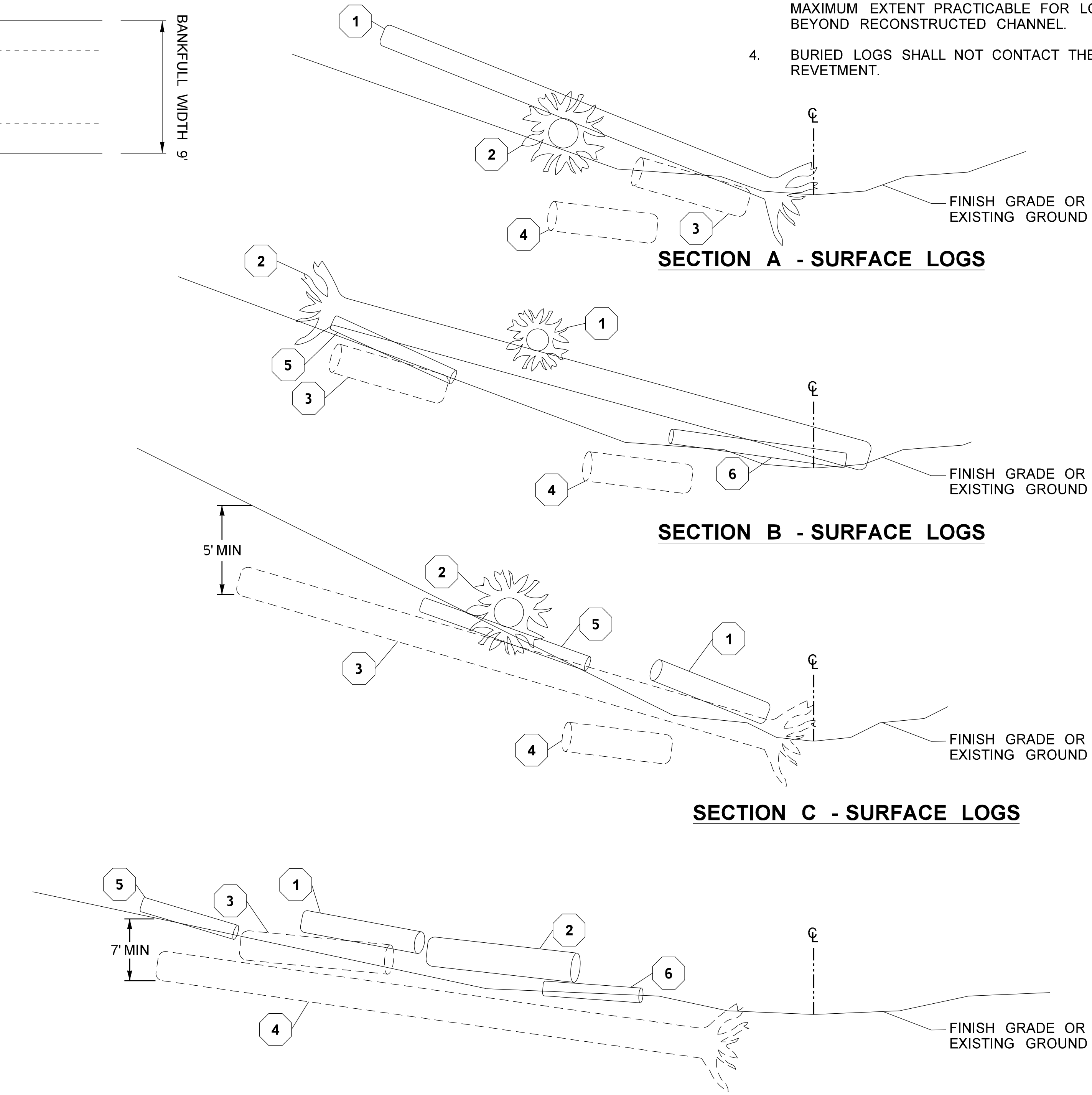
SHEETS

NOTES:

1. DASHED LINES INDICATE BURIED PIECES.
2. FINAL LOG PLACEMENT TO BE DIRECTED BY ENGINEER IN FIELD.
3. LIMIT DISTURBANCE TO EXISTING STREAMBANK TO MAXIMUM EXTENT PRACTICABLE FOR LOG PLACEMENT BEYOND RECONSTRUCTED CHANNEL.
4. BURIED LOGS SHALL NOT CONTACT THE BURIED REVETMENT.



PLAN VIEW



SECTION A - SURFACE LOGS

SECTION B - SURFACE LOGS

SECTION C - SURFACE LOGS

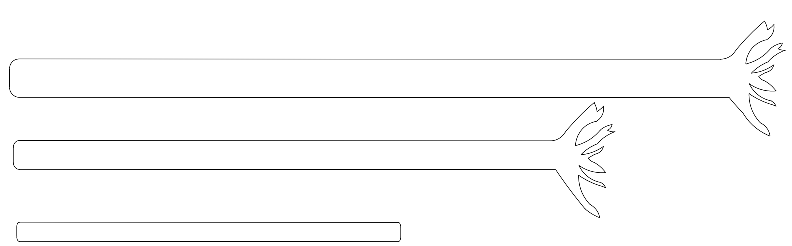
SECTION D - BURIED LOG

LEGEND

24" MIN DIA. 40' MIN. LENGTH, WITH ROOTWAD

18" MIN DIA. 30' MIN. LENGTH, WITH ROOTWAD

12" MIN DIA. 20' MIN. LENGTH, WITHOUT ROOTWAD



LARGE WOOD CLUSTER TYPE A

NTS

SR 8 MP 3.16 UNNAMED TRIBUTARY TO WILDCAT CREEK

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Washington State Department of Transportation

DAVID EVANS AND ASSOCIATES INC.

US 12 AND SR 8
GRAYS HARBOR COUNTY
REMOVE FISH BARRIERS

LARGE WOODY MATERIAL DETAILS

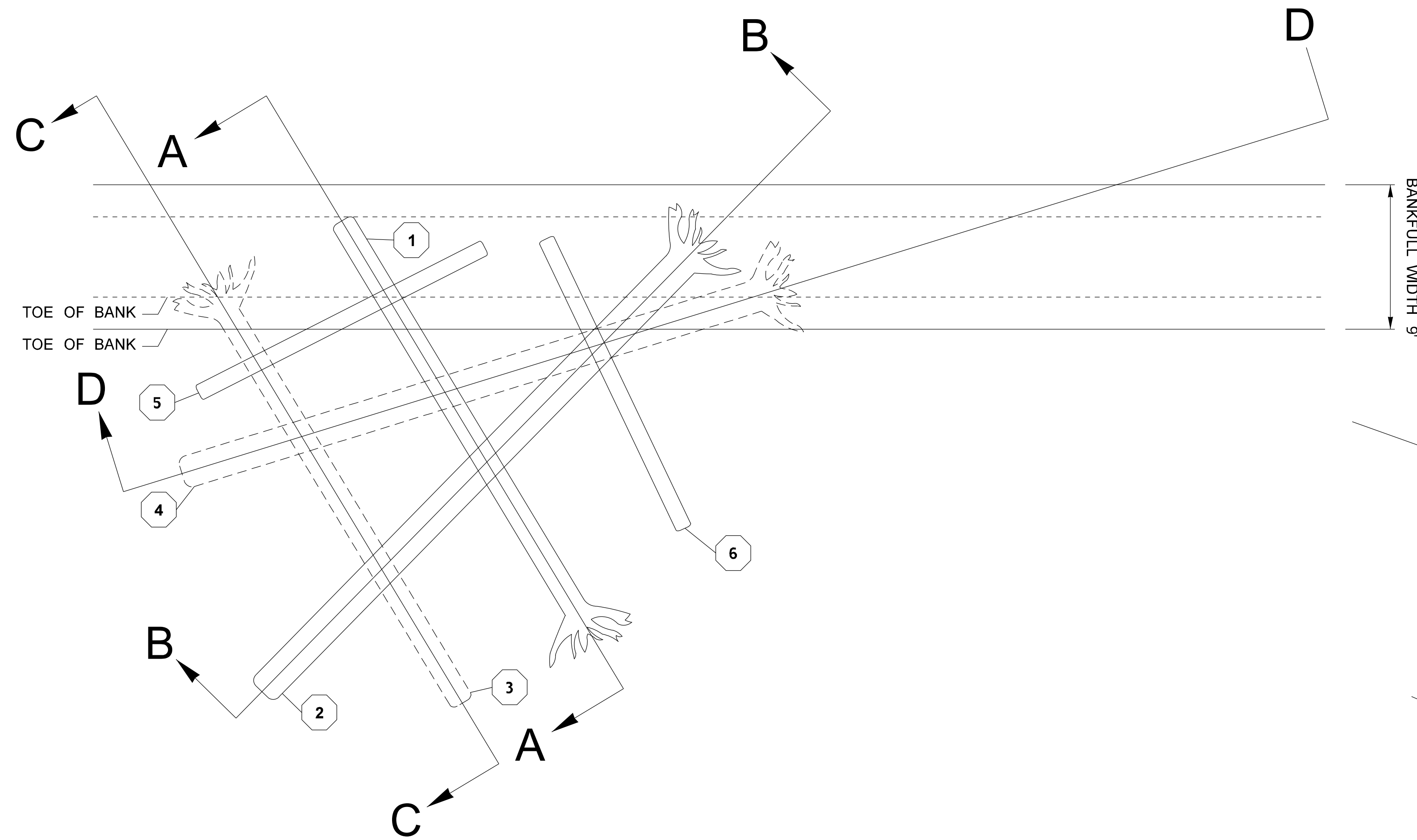
PLAN REF NO LWM3-D

SHEET OF SHEETS

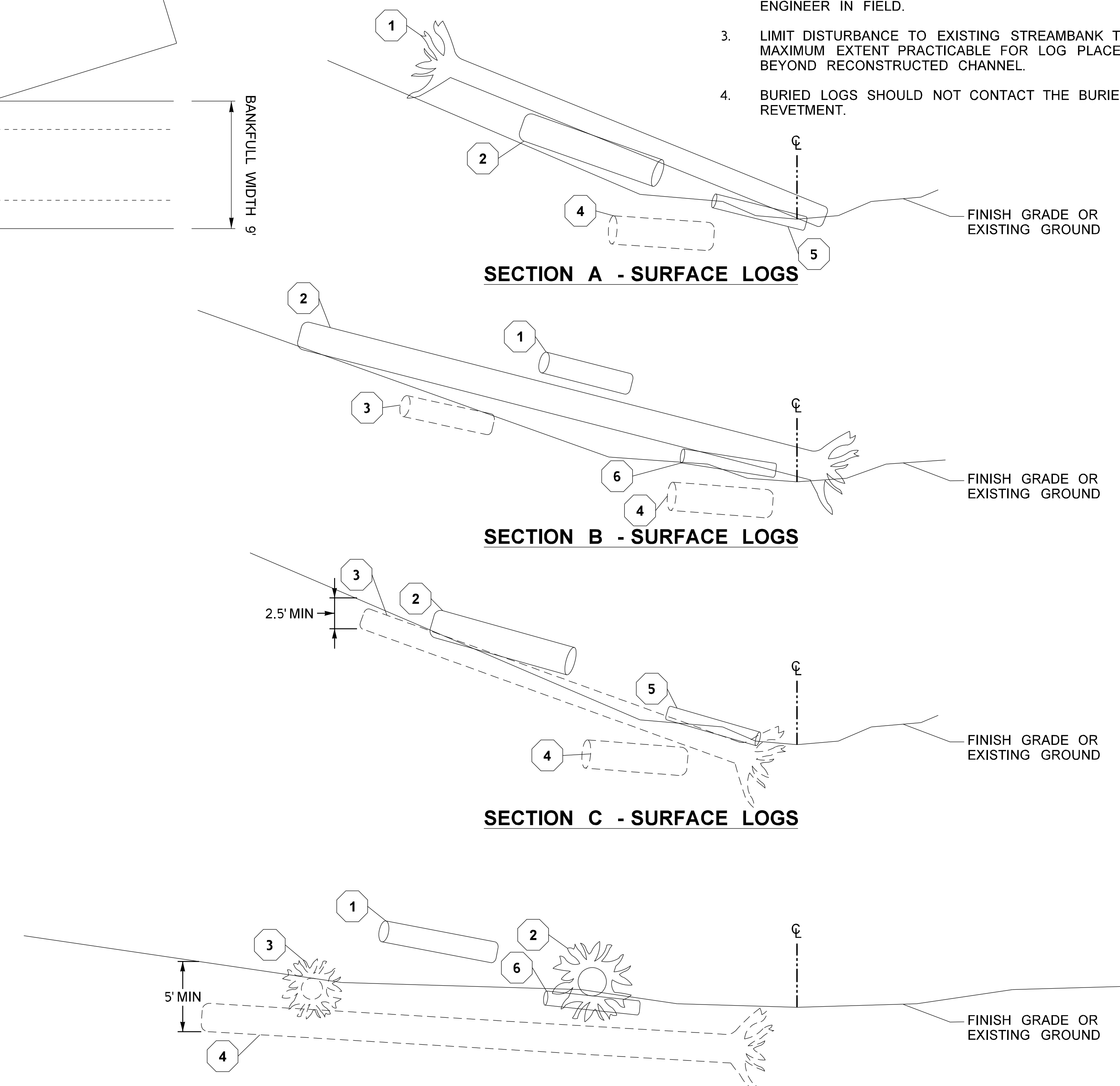
pw:\\HQOLYMAPPPW03P.WSDOT.LOC:WSDOT\Documents_HQ\Fish Passage\ORproj\008\3.16_TribToWildcatCr\Design_CAD_Sheets\Preliminary Design\SR8MP3.16_A_DE_LWM_001.dgn

NOTES:

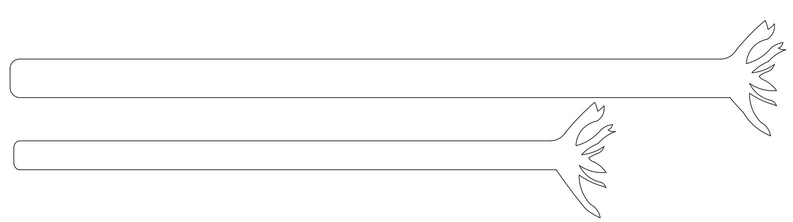
1. DASHED LINES INDICATE BURIED PIECES.
2. FINAL LOG PLACEMENT TO BE DIRECTED BY ENGINEER IN FIELD.
3. LIMIT DISTURBANCE TO EXISTING STREAMBANK TO MAXIMUM EXTENT PRACTICABLE FOR LOG PLACEMENT BEYOND RECONSTRUCTED CHANNEL.
4. BURIED LOGS SHOULD NOT CONTACT THE BURIED REVETMENT.



PLAN VIEW



LEGEND



24" MIN DIA. 40' MIN. LENGTH, WITH ROOTWAD

18" MIN DIA. 30' MIN. LENGTH, WITH ROOTWAD

12" MIN DIA. 20' MIN. LENGTH, WITHOUT ROOTWAD

LARGE WOOD CLUSTER TYPE B

NTS

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TIME	5:53:17 PM			
DATE	10/13/2022			
PLOTTED BY	Rhw			
DESIGNED BY	K. COMINGS			
ENTERED BY	R. WILCOX			
CHECKED BY	J. GAGE			
PROJ. ENGR.	B. ELLIOTT			
REGIONAL ADM.	S. ROARK	REVISION	DATE	BY

REGION NO. 10 | STATE WASH | FED.AID PROJ.NO. ARPA001

JOB NUMBER 21C522

CONTRACT NO. XL6115 | LOCATION NO.

P.E. STAMP BOX DATE

P.E. STAMP BOX DATE

Washington State Department of Transportation

DAVID EVANS AND ASSOCIATES INC.

SR 8 MP 3.16 UNNAMED TRIBUTARY TO WILDCAT CREEK

US 12 AND SR 8
GRAYS HARBOR COUNTY
REMOVE FISH BARRIERS

LARGE WOODY MATERIAL DETAILS

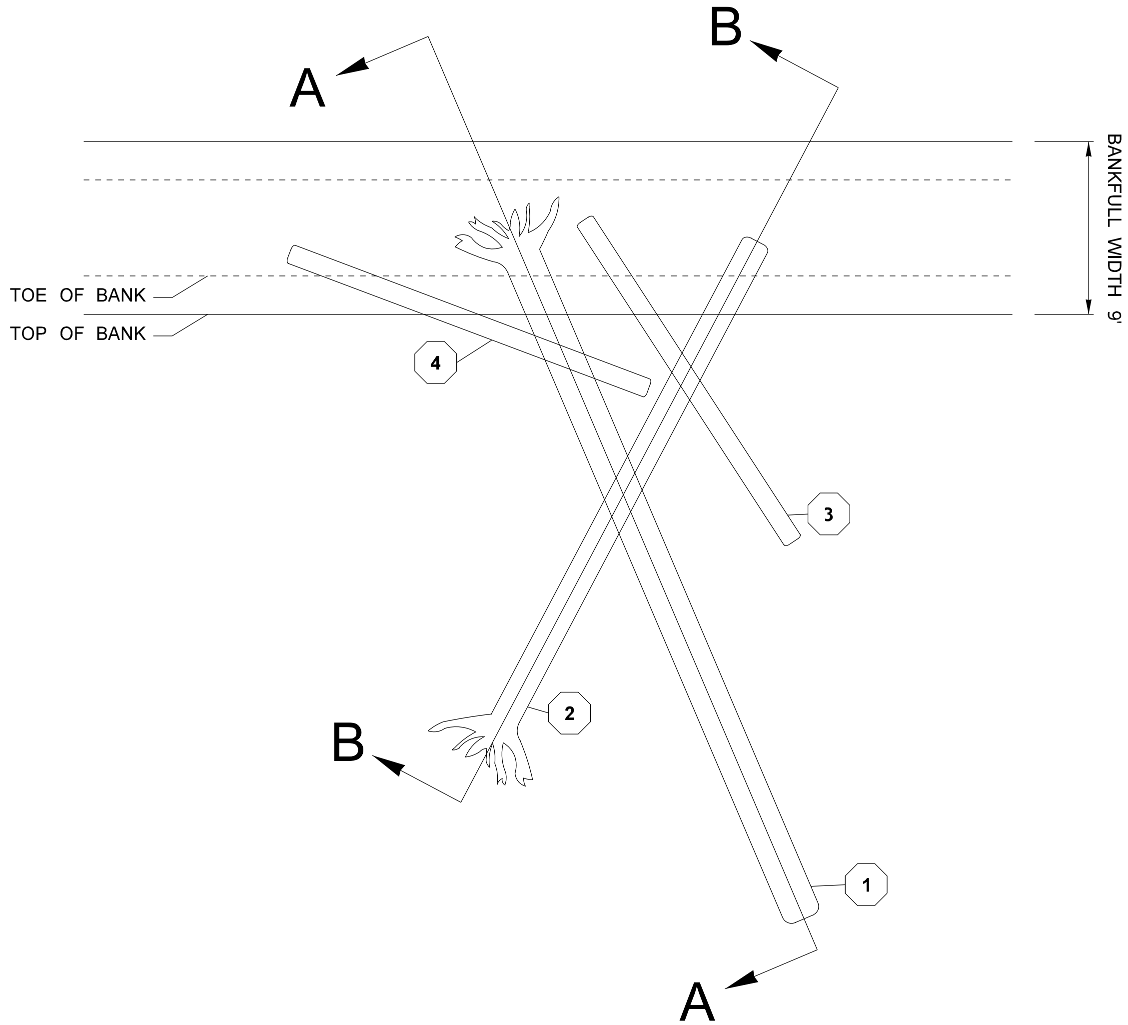
PLAN REF NO LWM4-D

SHEET OF SHEETS

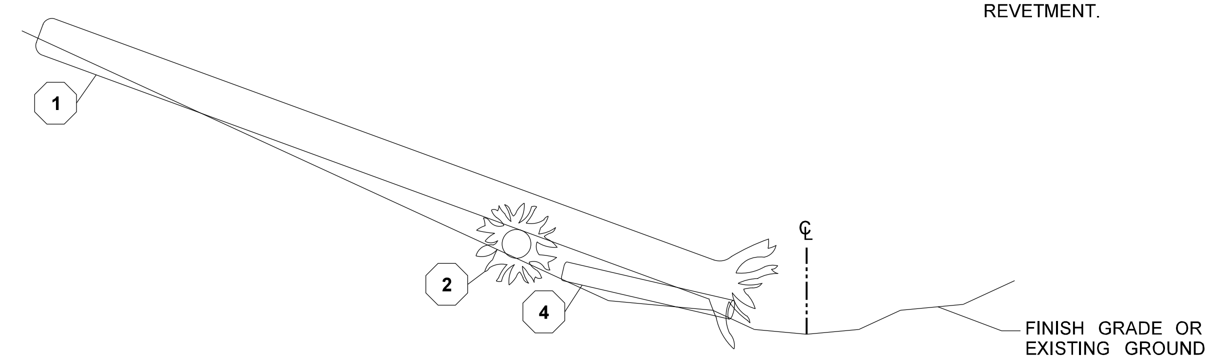
pw:\\HQOLYMAPPPW03P.WSDOT.LOC:WSDOT\Documents_HQ\Fish Passage\ORproj\008\3.16_TribToWildcatCr\Design_CAD_Sheets\Preliminary Design\SR8MP3.16_A_DE_LWM_002.dgn

NOTES:

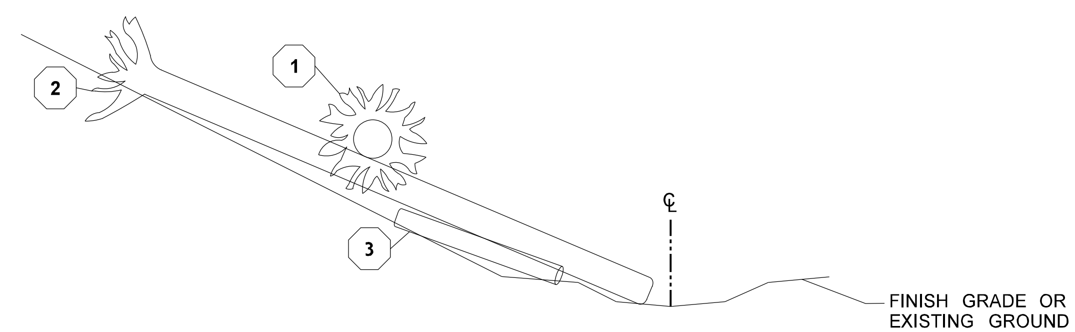
1. FINAL LOG PLACEMENT TO BE DIRECTED BY ENGINEER IN FIELD.
2. LIMIT DISTURBANCE TO EXISTING STREAMBANK TO MAXIMUM EXTENT PRACTICABLE FOR LOG PLACEMENT BEYOND RECONSTRUCTED CHANNEL.
3. BURIED LOGS SHALL NOT CONTACT THE BURIED REVETMENT.



PLAN VIEW



SECTION A - SECTION THROUGH LOG 1



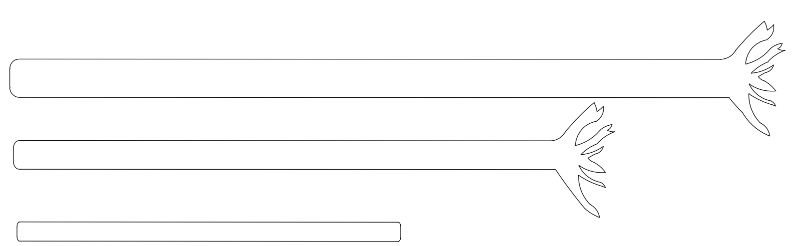
SECTION A - SECTION THROUGH LOG 2

LEGEND

24" MIN DIA. 40' MIN. LENGTH, WITH ROOTWAD

18" MIN DIA. 30' MIN. LENGTH, WITH ROOTWAD

12" MIN DIA. 20' MIN. LENGTH, WITHOUT ROOTWAD



LARGE WOOD CLUSTER TYPE D

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DATE	10/13/2022
PLOTTED BY	Rhw
DESIGNED BY	K. COMINGS
ENTERED BY	R. WILCOX
CHECKED BY	J. GAGE
PROJ. ENGR.	B. ELLIOTT
REGIONAL ADM.	S. ROARK

REVISION | DATE | BY

REGION NO. 10 | STATE WASH

FED.AID PROJ.NO. ARPA001

JOB NUMBER 21C522

CONTRACT NO. XL6115

LOCATION NO.

P.E. STAMP BOX DATE

P.E. STAMP BOX DATE

Washington State Department of Transportation

DAVID EVANS AND ASSOCIATES INC.

SR 8 MP 3.16 UNNAMED TRIBUTARY TO WILDCAT CREEK

US 12 AND SR 8
GRAYS HARBOR COUNTY
REMOVE FISH BARRIERS

LARGE WOODY MATERIAL DETAILS

PLAN REF NO LWM5-D

SHEET OF SHEETS

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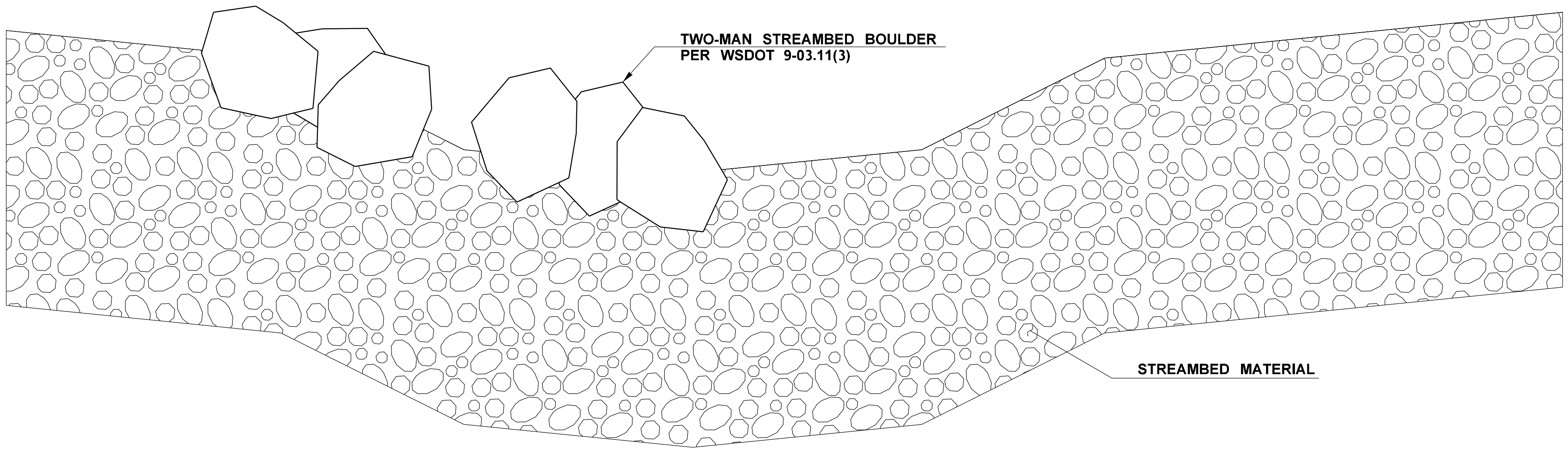
NOTES:

1. STREAMBED BOULDERS TO BE EMBEDDED IN STREAMBED BY 50 TO 80 PERCENT OF THEIR HEIGHT.
2. STREAMBED MATERIAL SHALL CONSIST OF A WELL GRADED MIX OF 50 PERCENT 6" STREAMBED COBBLES (9-03.11(2)) AND 50 PERCENT STREAMBED SEDIMENT (9-03.11(1)).



BOULDER CLUSTER DETAIL

NTS

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PLOTTED BY	Rhw			
DESIGNED BY	K. COMINGS			
ENTERED BY	R. WILCOX			
CHECKED BY	J. GAGE			
PROJ. ENGR.	B. ELLIOTT			
REGIONAL ADM.	S. ROARK	REVISION	DATE	BY

REGION NO. 10 | STATE WASH | FED.AID PROJ.NO. ARPA001

JOB NUMBER 21C522

CONTRACT NO. XL6115 | LOCATION NO.

P.E. STAMP BOX DATE

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Washington State Department of Transportation

DAVID EVANS AND ASSOCIATES INC.

SR 8 MP 3.16 UNNAMED TRIBUTARY TO WILDCAT CREEK

US 12 AND SR 8
GRAYS HARBOR COUNTY
REMOVE FISH BARRIERS

LARGE WOODY MATERIAL DETAILS

PLAN REF NO LWM6-D

SHEET OF SHEETS

Appendix E: Manning’s Calculations

Manning’s n calculations were not required for this project.

Appendix F: Large Woody Material Calculations

WSDOT Large Woody Material for stream restoration metrics calculator

State Route# & MP	*US 12*		Key piece volume	*1.310*	*yd3*
Stream name	*Wildcat Creek*		Key piece/ft	*0.0335*	*per ft stream*
length of regrade[a]	*278*	*ft*	Total wood vol./ft	*0.3948*	*yd3/ft stream*
Bankfull width	*9*	*ft*	Total LWM[c] pieces/ft stream	*0.1159*	*per ft stream*
Habitat zone[b]	*Western WA*				

Log type	Diameter at midpoint (ft)	Length(ft) [d]	Volume (yd^3/log) [d]	Rootwad?	Qualifies as key piece?	No. LWM pieces	Total wood volume (yd^3)	DBH based on mid point diameter (ft)
A	2.00	40	4.65	yes	yes	17	79.12	2.19
B	1.50	30	1.96	yes	yes	11	21.60	1.63
C	1.00	20	0.58	no	no	16	9.31	1.16
D			0.00				0.00	
E			0.00				0.00	
F			0.00				0.00	
G			0.00				0.00	
H			0.00				0.00	
I			0.00				0.00	
J			0.00				0.00	
K			0.00				0.00	
L			0.00				0.00	
M			0.00				0.00	
N			0.00				0.00	
O			0.00				0.00	
P			0.00				0.00	

	No. of key pieces	Total No. of LWM pieces	Total LWM volume (yd^3)
Design	28	44	110.0
Targets	**9**	**32**	**109.8**

SR 8 MP 3.16 Unnamed Tributary to Wildcat Creek

Large Wood Structure Stability Analysis

TABLE OF CONTENTS

Date of Last Revision: September 22, 2022

Designer: Roxanne Wilcox

Reviewed by: Karen Comings, P.E.

Large Wood Structure Stability Analysis Spreadsheet was developed by Michael Rafferty, P.E.
Version 1.1

Reference for Companion Paper:

Rafferty, M. 2016. *Computational Design Tool for Evaluating the Stability of Large Wood Structures.* Technical Note TN-103.1. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, National Stream & Aquatic Ecology Center.

SR 8 MP 3.16 Unnamed Tributary to Wildcat Creek
Factors of Safety and Design Constants

Spreadsheet developed by
Michael Rafferty, P.E.

Symbol	Description	Value
FS_V	Factor of Safety for Vertical Force Balance	**1.50**
FS_H	Factor of Safety for Horizontal Force Balance	**1.50**
FS_M	Factor of Safety for Moment Force Balance	**1.50**

Symbol	Description	Units	Value
C_{Lrock}	Coefficient of lift for submerged boulder (D'Aoust, 2000)	-	0.17
C_{Drock}	Coefficient of drag for submerged boulder (Schultz, 1954)	-	0.85
g	Gravitational acceleration constant	ft/s^2	32.174
DF_{RW}	Diameter factor for rootwad ($DF_{RW} = D_{RW}/D_{TS}$)	-	3.00
LF_{RW}	Length factor for rootwad ($LF_{RW} = L_{RW}/D_{TS}$)	-	1.50
SG_{rock}	Specific gravity of quartz particles	-	2.65
γ_{rock}	Dry unit weight of boulders	lb/ft^3	165.0
γ_w	Specific weight of water at 50ºF	lb/ft^3	62.40
η	Rootwad porosity from NRCS Tech Note 15 (2001)	-	0.20
ν	Kinematic viscosity of water at 50ºF	ft/s^2	1.41E-05

SR 8 MP 3.16 Unnamed Tributary to Wildcat Creel
Hydrologic and Hydraulic Inputs

Spreadsheet developed by
Michael Rafferty, P.E.

Average Return Interval (ARI) of Design Discharge: 100 yr

Site ID	Proposed Station	Design Discharge, Q_{des} (cfs)	Maximum Depth, d_w (ft)	Average Velocity, u_{avg} (ft/s)	Bankfull Width, W_{BF} (ft)	Wetted Area, A_W (ft^2)	Radius of Curvature, R_c (ft)
Wildcat	6+40	75	1.82	4.80	9.1	15	50

SR 8 MP 3.16 Unnamed Tributary to Wild
Stream Bed Substrate Properties

Spreadsheet developed by
Michael Rafferty, P.E.

Site ID	Proposed Station	Stream bed D_{50} (mm)	Stream Bed Substrate Grain Size Class	Bed Soil Class	Dry Unit Weight[1], γ_{bed} (lb/ft^3)	Buoyant Unit Weight, γ'_{bed} (lb/ft^3)	Friction Angle, ϕ_{bed} (deg)
Wildcat	6+40	33.00	Very coarse gravel	5	128.3	79.9	40

Source: Compiled from Julien (2010) and Shen and Julien (1993); soil classes from NRCS Table TS14E–2 Soil classification

[1] γ_{bed} (kg/m^3) = 1,600 + 300 log D_{50} (mm) (from Julien 2010)

1 kg/m^3 = 0.062 1 lb/ft^3

SR 8 MP 3.16 Unnamed Tributary t
Bank Soil Properties

Spreadsheet developed by
Michael Rafferty, P.E.

Site ID	Proposed Station	Bank Soils (from field observations)	Bank Soil Class	Dry Unit Weight, γ_{bank} (lb/ft^3)	Buoyant Unit Weight, γ'_{bank} (lb/ft^3)	Friction Angle, ϕ_{bank} (deg)
Wildcat	6+40	Gravel/cobble	4	137.0	85.3	41

SR 8 MP 3.16 Unnamed Tributary to Wildcat Creek
Large Wood Properties

Spreadsheet developed by
Michael Rafferty, P.E.

Project Location: West Coast

Timber Unit Weights			Air-dried[1] γ_{Td} (lb/ft^3)	Green[2] γ_{Tgr} (lb/ft^3)
Selected Species	**Common Name**	**Scientific Name**		
Tree Type #1:	**Douglas-fir, Coast**	Pseudotsuga menziesii var. menzi.	33.5	38.0
Tree Type #2:				
Tree Type #3:				
Tree Type #4:				
Tree Type #5:				
Tree Type #6:				
Tree Type #7:				
Tree Type #8:				
Tree Type #9:				
Tree Type #10:				

[1] **Air-dried unit weight,** γ_{Td} = Average unit weight of wood after exposure to air on a 12% moisture content volume basis. Air-dried unit weight is used in the force balance calculations for the portion of wood that is above the proposed thalweg elevation (assuming unsaturated conditions).

[2] **Green unit weight,** γ_{Tgr} = Average unit weight of freshly sawn wood when the cell walls are completely saturated with water. Green unit weight is used in the force balance calculations as a conservative estimate of the unit weight for the portion of wood that is below the proposed thalweg elevation (assuming saturated conditions). For comparison, Thevenet, Citterio, & Piegay (1998) determined wood unit weight typically increases by more than 100% after less than 24 hours exposure to water.

Source for timber unit weights:

U.S. Department of Agriculture, U.S. Forest Service. (2009) Specific Gravity and Other Properties of Wood and Bark for 156 Tree Species Found in North America. Research Note NRS-38. Table 1A.

SR 8 MP 3.16 Unnamed Tributary to Wildcat Creek

Spreadsheet developed by
Michael Rafferty, P.E.

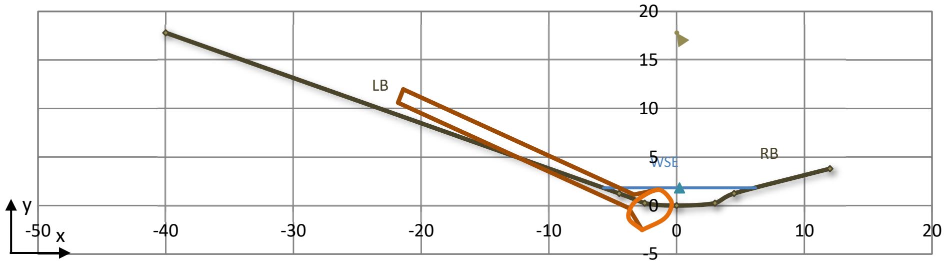
Single Log Stability Analysis Model Inputs

Site ID	Structure Type	Structure Position	Meander	Station	d_w (ft)	R_c/W_{BF}	u_{des} (ft/s)
Wildcat	Rootwad	Left bank	Straight	6+40	1.82	5.49	4.80

Multi-Log Structures	Layer	Log ID
	Stacked	A Log #1

Channel Geometry Coordinates		
Proposed	x (ft)	y (ft)
Fldpln LB	-40.00	17.80
Top LB	-4.50	1.25
Toe LB	-2.50	0.25
Thalweg	0.00	0.00
Toe RB	3.00	0.25
Top RB	4.50	1.25
Fldpln RB	12.00	3.80

Proposed Cross-Section and Structure Geometry (Looking D/S)

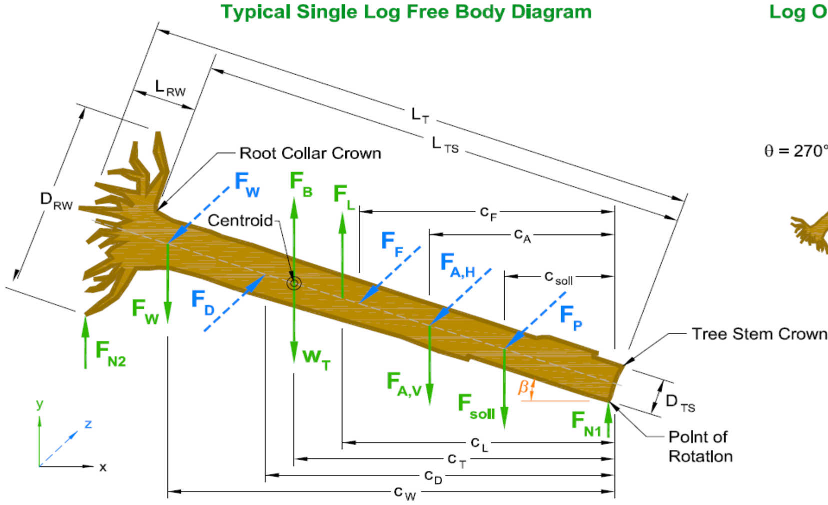


Wood Species	Rootwad	L_T (ft)	D_{TS} (ft)	L_{RW} (ft)	D_{RW} (ft)	γ_{Td} (lb/ft^3)	γ_{Tgr} (lb/ft^3)
Douglas-fir, Coast	Yes	30.0	1.50	2.25	4.50	33.5	38.0

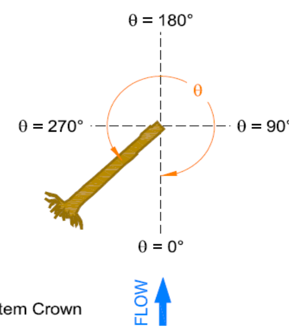
Structure Geometry	θ (deg)	β (deg)	Define Fixed Point	x_T (ft)	y_T (ft)	$y_{T,min}$ (ft)	$y_{T,max}$ (ft)	A_{Tp} (ft^2)
	135.0	23.0	Root collar: Bottom	-3.75	-0.25	-2.51	11.97	6.79

Soils	Material	γ_s (lb/ft^3)	γ'_s (lb/ft^3)	ϕ (deg)	Soil Class	$L_{T,em}$ (ft)	$d_{b,max}$ (ft)	$d_{b,avg}$ (ft)
Stream Bed	Very coarse gravel	128.3	79.9	40.0	5	0.97	0.00	0.00
Bank	Gravel/cobble	137.0	85.3	41.0	4	0.00	0.00	0.00

Typical Single Log Free Body Diagram



Log Orientation (Plan View)



Vertical Force Analysis

Net Buoyancy Force

Wood	V_{TS} (ft^3)	V_{RW} (ft^3)	V_T (ft^3)	W_T (lbf)	F_B (lbf)
↑WSE	42.8	0.0	42.8	1,436	0
↓WS↑Thw	6.2	7.9	14.0	471	876
↓Thalweg	0.1	5.9	6.0	228	374
Total	49.0	13.8	62.8	2,134	1,249

Lift Force

C_{LT}	0.00
F_L (lbf)	0

Vertical Force Balance

F_B (lbf)	1,249
F_L (lbf)	0
W_T (lbf)	2,134
F_{soil} (lbf)	0
$F_{W,V}$ (lbf)	0
$F_{A,V}$ (lbf)	0
ΣF_V (lbf)	885
FS_V	1.71

Soil Ballast Force

Soil	V_{dry} (ft^3)	V_{sat} (ft^3)	V_{soil} (ft^3)	F_{soil} (lbf)
Bed	0.0	0.0	0.0	0
Bank	0.0	0.0	0.0	0
Total	0.0	0.0	0.0	0

Horizontal Force Analysis

Drag Force

A_{Tp} / A_W	Fr_L	C_{Di}	C_w	C_D*	F_D (lbf)
0.45	0.69	0.81	0.43	4.25	645

Horizontal Force Balance

F_D (lbf)	645
F_P (lbf)	0
F_F (lbf)	764
$F_{W,H}$ (lbf)	0
$F_{A,H}$ (lbf)	0
ΣF_H (lbf)	119
FS_H	1.18

Passive Soil Pressure / Friction Force

Soil	K_P	F_P (lbf)	L_{Tf} (ft)	μ	F_F (lbf)
Bed	4.60	0	2.98	0.84	145
Bank	4.81	0	12.30	0.87	619
Total	-	0	15.28	-	764

Moment Force Balance

Driving Moment Centroids / Resisting Moment Centroids

$c_{T,B}$ (ft)	c_L (ft)	c_D (ft)	$c_{T,W}$ (ft)	c_{soil} (ft)	$c_{F\&N}$ (ft)	c_P (ft)
17.4	0.0	26.3	17.4	0.0	23.4	0.0

*Distances are from the stem tip

Point of Rotation: Rootwad

Moment Force Balance

M_d (lbf)	16,728
M_r (lbf)	34,787
FS_M	2.08

Anchor Forces

Additional Soil Ballast

V_{Adry} (ft^3)	V_{Awet} (ft^3)	c_{Asoil} (ft)	$F_{A,Vsoil}$ (lbf)	$F_{A,HP}$ (lbf)
			0	0

Mechanical Anchors

Type	c_{Am} (ft)	Soils	F_{Am} (lbf)
			0
			0

Boulder Ballast

Position	D_r (ft)	c_{Ar} (ft)	$V_{r,dry}$ (ft^3)	$V_{r,wet}$ (ft^3)	W_r (lbf)	$F_{L,r}$ (lbf)	$F_{D,r}$ (lbf)	$F_{A,Vr}$ (lbf)	$F_{A,Hr}$ (lbf)
								0	0
								0	0
								0	0

SR 8 MP 3.16 Unnamed Tributary to Wildcat Creek

Spreadsheet developed by
Michael Rafferty, P.E.

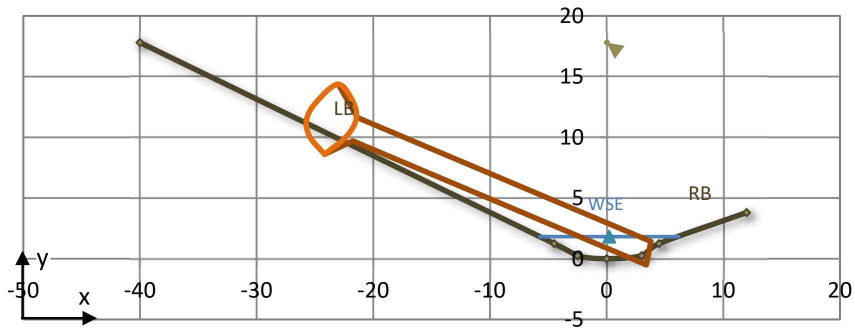
Single Log Stability Analysis Model Inputs

Site ID	Structure Type	Structure Position	Meander	Station	d_w (ft)	R_c/W_{BF}	u_{des} (ft/s)
Wildcat	Rootwad	Left bank	Straight	6+40	1.82	5.49	4.80

Multi-Log Structures	Layer	Log ID
	Stacked	A Log #2

Channel Geometry Coordinates		
Proposed	x (ft)	y (ft)
Fldpln LB	-40.00	17.80
Top LB	-4.50	1.25
Toe LB	-2.50	0.25
Thalweg	0.00	0.00
Toe RB	3.00	0.25
Top RB	4.50	1.25
Fldpln RB	12.00	3.80

Proposed Cross-Section and Structure Geometry (Looking D/S)

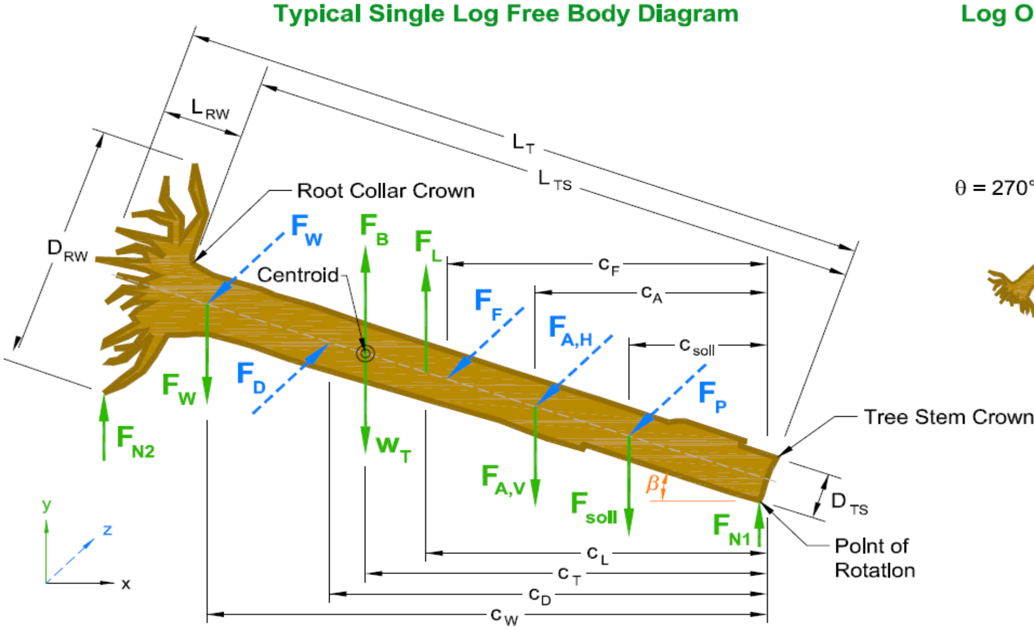


Wood Species	Rootwad	L_T (ft)	D_{TS} (ft)	L_{RW} (ft)	D_{RW} (ft)	γ_{Td} (lb/ft^3)	γ_{Tgr} (lb/ft^3)
Douglas-fir, Coast	Yes	40.0	2.00	3.00	6.00	33.5	38.0

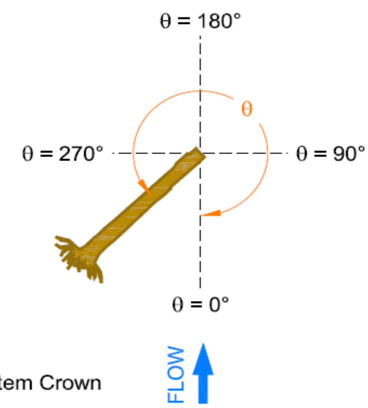
Structure Geometry	θ (deg)	β (deg)	Define Fixed Point	x_T (ft)	y_T (ft)	$y_{T,min}$ (ft)	$y_{T,max}$ (ft)	A_{Tp} (ft^2)
	225.0	-16.0	Stem tip: Bottom	3.40	-0.50	-0.50	14.37	5.98

Soils	Material	γ_s (lb/ft^3)	γ'_s (lb/ft^3)	ϕ (deg)	Soil Class	$L_{T,em}$ (ft)	$d_{b,max}$ (ft)	$d_{b,avg}$ (ft)
Stream Bed	Very coarse gravel	128.3	79.9	40.0	5	0.00	0.00	0.00
Bank	Gravel/cobble	137.0	85.3	41.0	4	0.00	0.00	0.00

Typical Single Log Free Body Diagram



Log Orientation (Plan View)



Vertical Force Analysis

Net Buoyancy Force

Wood	V_{TS} (ft^3)	V_{RW} (ft^3)	V_T (ft^3)	W_T (lbf)	F_B (lbf)
↑WSE	100.8	32.7	133.4	4,476	0
↓WS↑Thw	15.0	0.0	15.0	503	936
↓Thalweg	0.5	0.0	0.5	18	30
Total	116.2	32.7	148.9	4,998	967

Lift Force

C_{LT}	0.00
F_L (lbf)	0

Vertical Force Balance

F_B (lbf)	967
F_L (lbf)	0
W_T (lbf)	4,998
F_{soil} (lbf)	0
$F_{W,V}$ (lbf)	0
$F_{A,V}$ (lbf)	0
ΣF_V (lbf)	4,031
FS_V	5.17

Soil Ballast Force

Soil	V_{dry} (ft^3)	V_{sat} (ft^3)	V_{soil} (ft^3)	F_{soil} (lbf)
Bed	0.0	0.0	0.0	0
Bank	0.0	0.0	0.0	0
Total	0.0	0.0	0.0	0

Horizontal Force Analysis

Drag Force

A_{Tp} / A_W	Fr_L	C_{Di}	C_w	C_D*	F_D (lbf)
0.40	0.60	0.76	0.43	3.38	452

Horizontal Force Balance

F_D (lbf)	452
F_P (lbf)	0
F_F (lbf)	3,412
$F_{W,H}$ (lbf)	0
$F_{A,H}$ (lbf)	0
ΣF_H (lbf)	2,960
FS_H	7.55

Passive Soil Pressure / Friction Force

Soil	K_P	F_P (lbf)	L_{Tf} (ft)	μ	F_F (lbf)
Bed	4.60	0	3.40	0.84	2,556
Bank	4.81	0	1.10	0.87	857
Total	-	0	4.50	-	3,412

Moment Force Balance

Driving Moment Centroids / Resisting Moment Centroids

$c_{T,B}$ (ft)	c_L (ft)	c_D (ft)	$c_{T,W}$ (ft)	c_{soil} (ft)	$c_{F\&N}$ (ft)	c_P (ft)
23.0	0.0	4.2	23.0	0.0	1.2	0.0

*Distances are from the stem tip

Point of Rotation: Rootwad

Moment Force Balance

M_d (lbf)	31,355
M_r (lbf)	359,338
FS_M	11.46

Anchor Forces

Additional Soil Ballast

V_{Adry} (ft^3)	V_{Awet} (ft^3)	c_{Asoil} (ft)	$F_{A,Vsoil}$ (lbf)	$F_{A,HP}$ (lbf)
			0	0

Mechanical Anchors

Type	c_{Am} (ft)	Soils	F_{Am} (lbf)
			0
			0

Boulder Ballast

Position	D_r (ft)	c_{Ar} (ft)	$V_{r,dry}$ (ft^3)	$V_{r,wet}$ (ft^3)	W_r (lbf)	$F_{L,r}$ (lbf)	$F_{D,r}$ (lbf)	$F_{A,Vr}$ (lbf)	$F_{A,Hr}$ (lbf)
								0	0
								0	0
								0	0

Interaction Forces with Adjacent Logs

						Applied Forces from other Logs	
Log ID	Position	Link	c_{WI} (ft)	$F_{W,V}$ (lbf)	$F_{W,H}$ (lbf)	$F_{W,V}$ (lbf)	$F_{W,H}$ (lbf)
A Log #5	Below	Gravity	25.0	0	-456	0	0
A Log #6	Below	Gravity	5.0	-38	355	0	0
						0	0
						0	0

SR 8 MP 3.16 Unnamed Tributary to Wildcat Creek

Spreadsheet developed by
Michael Rafferty, P.E.

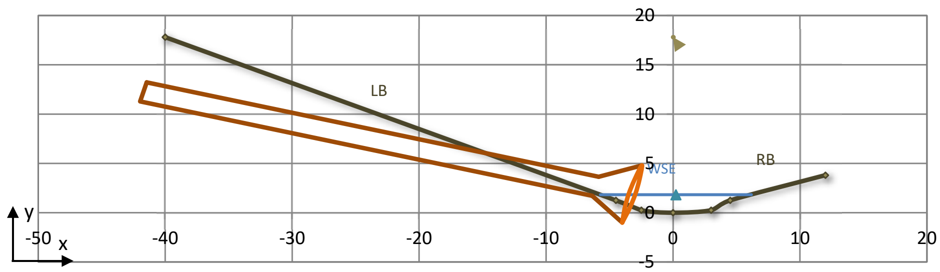
Single Log Stability Analysis Model Inputs

Site ID	Structure Type	Structure Position	Meander	Station	d_w (ft)	R_c/W_{BF}	u_{des} (ft/s)
Wildcat	Rootwad	Left bank	Straight	6+40	1.82	5.49	4.80

Multi-Log Structures	Layer	Log ID
	Stacked	A Log #3

Channel Geometry Coordinates		
Proposed	x (ft)	y (ft)
Fldpln LB	-40.00	17.80
Top LB	-4.50	1.25
Toe LB	-2.50	0.25
Thalweg	0.00	0.00
Toe RB	3.00	0.25
Top RB	4.50	1.25
Fldpln RB	12.00	3.80

Proposed Cross-Section and Structure Geometry (Looking D/S)

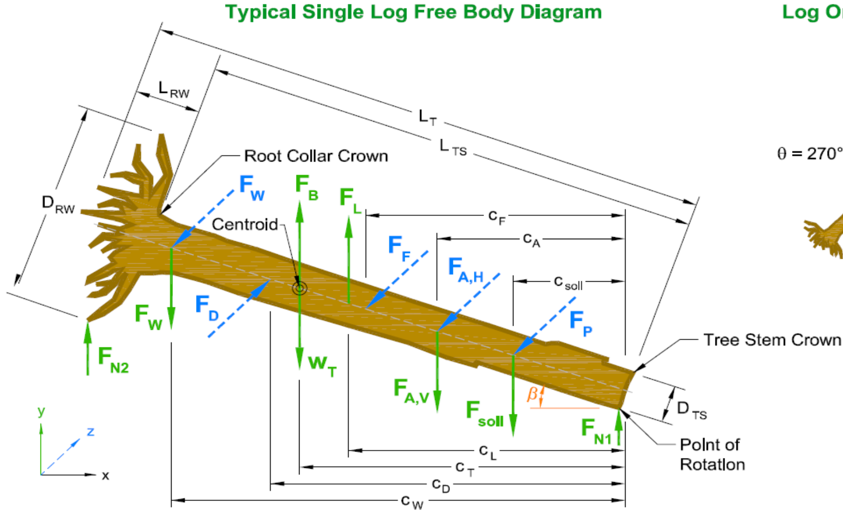


Wood Species	Rootwad	L_T (ft)	D_{TS} (ft)	L_{RW} (ft)	D_{RW} (ft)	γ_{Td} (lb/ft^3)	γ_{Tgr} (lb/ft^3)
Douglas-fir, Coast	Yes	40.0	2.00	3.00	6.00	33.5	38.0

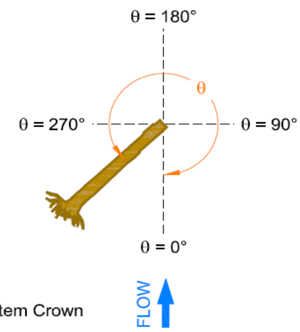
Structure Geometry	θ (deg)	β (deg)	Define Fixed Point	x_T (ft)	y_T (ft)	$y_{T,min}$ (ft)	$y_{T,max}$ (ft)	A_{Tp} (ft^2)
	85.0	15.0	Rootwad: Bottom	-4.00	-1.00	-1.00	13.22	80.67

Soils	Material	γ_s (lb/ft^3)	γ'_s (lb/ft^3)	φ (deg)	Soil Class	$L_{T,em}$ (ft)	$d_{b,max}$ (ft)	$d_{b,avg}$ (ft)
Stream Bed	Very coarse gravel	128.3	79.9	40.0	5	0.00	0.00	0.00
Bank	Gravel/cobble	137.0	85.3	41.0	4	27.74	5.26	2.64

Typical Single Log Free Body Diagram



Log Orientation (Plan View)



Vertical Force Analysis

Net Buoyancy Force

Wood	V_{TS} (ft^3)	V_{RW} (ft^3)	V_T (ft^3)	W_T (lbf)	F_B (lbf)
↑WSE	116.2	18.6	134.8	4,523	0
↓WS↑Thw	0.0	13.1	13.1	438	815
↓Thalweg	0.0	1.0	1.0	39	64
Total	116.2	32.7	148.9	5,000	879

Lift Force

C_{LT}	0.00
F_L (lbf)	0

Vertical Force Balance

F_B (lbf)	879
F_L (lbf)	0
W_T (lbf)	5,000
F_{soil} (lbf)	20,000
$F_{W,V}$ (lbf)	0
$F_{A,V}$ (lbf)	0
ΣF_V (lbf)	24,122
FS_V	28.45

Soil Ballast Force

Soil	V_{dry} (ft^3)	V_{sat} (ft^3)	V_{soil} (ft^3)	F_{soil} (lbf)
Bed	0.0	0.0	0.0	0
Bank	146.0	0.0	146.0	20,000
Total	146.0	0.0	146.0	20,000

Horizontal Force Analysis

Drag Force

A_{Tp} / A_W	Fr_L	C_{Di}	C_w	C_D*	F_D (lbf)
5.36	0.60	1.02	0.00	#NUM!	#NUM!

Horizontal Force Balance

F_D (lbf)	#NUM!
F_P (lbf)	48,150
F_F (lbf)	20,932
$F_{W,H}$ (lbf)	0
$F_{A,H}$ (lbf)	0
ΣF_H (lbf)	#NUM!
FS_H	#NUM!

#NUM!

Passive Soil Pressure / Friction Force

Soil	K_P	F_P (lbf)	L_{Tf} (ft)	μ	F_F (lbf)
Bed	4.60	0	2.00	0.84	1,015
Bank	4.81	48,150	37.90	0.87	19,917
Total	-	48,150	39.90	-	20,932

Moment Force Balance

Driving Moment Centroids / Resisting Moment Centroids

$c_{T,B}$ (ft)	c_L (ft)	c_D (ft)	$c_{T,W}$ (ft)	c_{soil} (ft)	$c_{F\&N}$ (ft)	c_P (ft)
23.0	0.0	#NUM!	23.0	13.8	18.9	18.4

*Distances are from the stem tip

Point of Rotation:	Stem Tip

Moment Force Balance

M_d (lbf)	#NUM!
M_r (lbf)	2,055,972
FS_M	#NUM!

#NUM!

Anchor Forces

Additional Soil Ballast

V_{Adry} (ft^3)	V_{Awet} (ft^3)	c_{Asoil} (ft)	$F_{A,Vsoil}$ (lbf)	$F_{A,HP}$ (lbf)
			0	0

Mechanical Anchors

Type	c_{Am} (ft)	Soils	F_{Am} (lbf)
			0
			0

Boulder Ballast

Position	D_r (ft)	c_{Ar} (ft)	$V_{r,dry}$ (ft^3)	$V_{r,wet}$ (ft^3)	W_r (lbf)	$F_{L,r}$ (lbf)	$F_{D,r}$ (lbf)	$F_{A,Vr}$ (lbf)	$F_{A,Hr}$ (lbf)
								0	0
								0	0
								0	0

SR 8 MP 3.16 Unnamed Tributary to Wildcat Creek

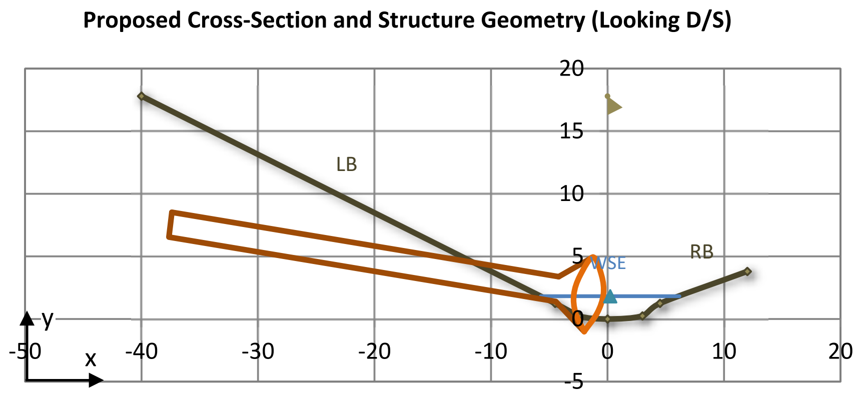
Spreadsheet developed by
Michael Rafferty, P.E.

Single Log Stability Analysis Model Inputs

Site ID	Structure Type	Structure Position	Meander	Station	d_w (ft)	R_c/W_{BF}	u_{des} (ft/s)
Wildcat	Rootwad	Left bank	Straight	6+40	1.82	5.49	4.80

Multi-Log Structures	Layer	Log ID
	Key Log	A Log #4

Channel Geometry Coordinates		
Proposed	x (ft)	y (ft)
Fldpln LB	-40.00	17.80
Top LB	-4.50	1.25
Toe LB	-2.50	0.25
Thalweg	0.00	0.00
Toe RB	3.00	0.25
Top RB	4.50	1.25
Fldpln RB	12.00	3.80

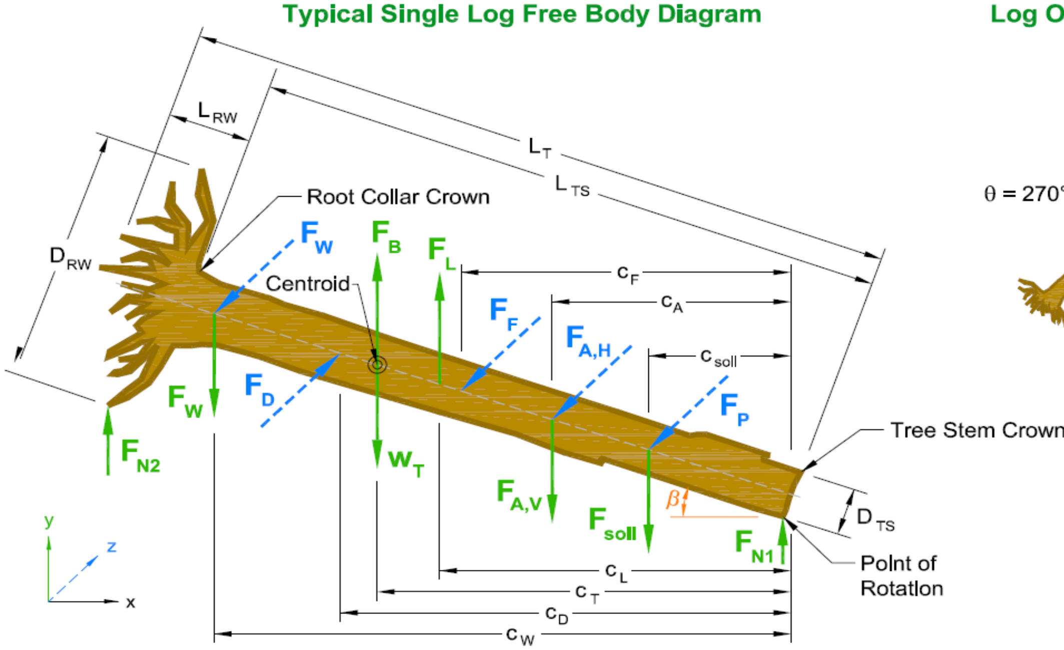


Wood Species	Rootwad	L_T (ft)	D_{TS} (ft)	L_{RW} (ft)	D_{RW} (ft)	γ_{Td} (lb/ft^3)	γ_{Tgr} (lb/ft^3)
Douglas-fir, Coast	Yes	40.0	2.00	3.00	6.00	33.5	38.0

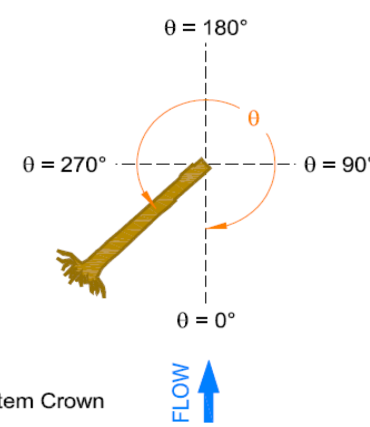
Structure Geometry	θ (deg)	β (deg)	Define Fixed Point	x_T (ft)	y_T (ft)	$y_{T,min}$ (ft)	$y_{T,max}$ (ft)	A_{Tp} (ft^2)
	65.0	8.0	Rootwad: Bottom	-2.00	-1.00	-1.00	8.53	76.86

Soils	Material	γ_s (lb/ft^3)	γ'_s (lb/ft^3)	φ (deg)	Soil Class	$L_{T,em}$ (ft)	$d_{b,max}$ (ft)	$d_{b,avg}$ (ft)
Stream Bed	Very coarse gravel	128.3	79.9	40.0	5	0.00	0.00	0.00
Bank	Gravel/cobble	137.0	85.3	41.0	4	28.86	8.06	4.04

Typical Single Log Free Body Diagram



Log Orientation (Plan View)



Vertical Force Analysis

Net Buoyancy Force

Wood	V_{TS} (ft^3)	V_{RW} (ft^3)	V_T (ft^3)	W_T (lbf)	F_B (lbf)
↑WSE	115.6	19.0	134.6	4,516	0
↓WS↑Thw	0.6	12.5	13.1	439	818
↓Thalweg	0.0	1.2	1.2	45	74
Total	116.2	32.7	148.9	5,001	892

Lift Force

C_{LT}	0.00
F_L (lbf)	0

Vertical Force Balance

F_B (lbf)	892
F_L (lbf)	0
W_T (lbf)	5,001
F_{soil} (lbf)	31,854
$F_{W,V}$ (lbf)	0
$F_{A,V}$ (lbf)	0
ΣF_V (lbf)	35,963
FS_V	41.34

Soil Ballast Force

Soil	V_{dry} (ft^3)	V_{sat} (ft^3)	V_{soil} (ft^3)	F_{soil} (lbf)
Bed	0.0	0.0	0.0	0
Bank	232.5	0.0	232.5	31,854
Total	232.5	0.0	232.5	31,854

Horizontal Force Analysis

Drag Force

A_{Tp} / A_W	Fr_L	C_{Di}	C_w	C_D*	F_D (lbf)
5.11	0.60	1.21	0.00	#NUM!	#NUM!

Horizontal Force Balance

F_D (lbf)	#NUM!
F_P (lbf)	76,688
F_F (lbf)	31,205
$F_{W,H}$ (lbf)	0
$F_{A,H}$ (lbf)	0
ΣF_H (lbf)	#NUM!
FS_H	#NUM!

#NUM!

Passive Soil Pressure / Friction Force

Soil	K_P	F_P (lbf)	L_{Tf} (ft)	µ	F_F (lbf)
Bed	4.60	0	2.00	0.84	1,592
Bank	4.81	76,688	35.90	0.87	29,613
Total	-	76,688	37.90	-	31,205

Moment Force Balance

Driving Moment Centroids / Resisting Moment Centroids

$c_{T,B}$ (ft)	c_L (ft)	c_D (ft)	$c_{T,W}$ (ft)	c_{soil} (ft)	$c_{F\&N}$ (ft)	c_P (ft)
23.0	0.0	#NUM!	23.0	14.4	17.9	19.2

*Distances are from the stem tip

Point of Rotation: Stem Tip

Moment Force Balance

M_d (lbf)	#NUM!
M_r (lbf)	3,216,844
FS_M	#NUM!

#NUM!

Anchor Forces

Additional Soil Ballast

V_{Adry} (ft^3)	V_{Awet} (ft^3)	c_{Asoil} (ft)	$F_{A,Vsoil}$ (lbf)	$F_{A,HP}$ (lbf)
			0	0

Mechanical Anchors

Type	c_{Am} (ft)	Soils	F_{Am} (lbf)
			0
			0

Boulder Ballast

Position	D_r (ft)	c_{Ar} (ft)	$V_{r,dry}$ (ft^3)	$V_{r,wet}$ (ft^3)	W_r (lbf)	$F_{L,r}$ (lbf)	$F_{D,r}$ (lbf)	$F_{A,Vr}$ (lbf)	$F_{A,Hr}$ (lbf)
								0	0
								0	0
								0	0

SR 8 MP 3.16 Unnamed Tributary to Wildcat Creek

Spreadsheet developed by
Michael Rafferty, P.E.

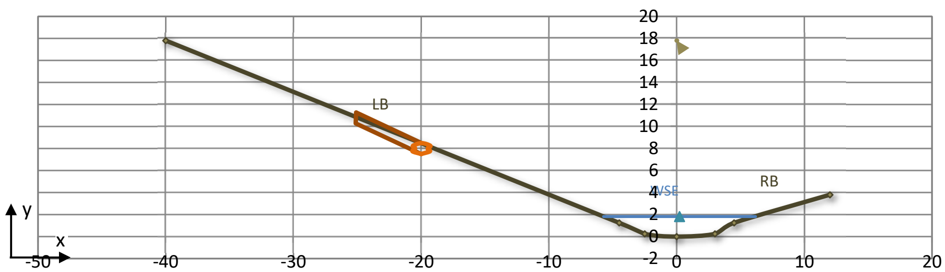
Single Log Stability Analysis Model Inputs

Site ID	Structure Type	Structure Position	Meander	Station	d_w (ft)	R_c/W_{BF}	u_{des} (ft/s)
Wildcat	Rootwad	Left bank	Straight	6+40	1.82	5.49	4.80

Multi-Log Structures	Layer	Log ID
	Stacked	A Log #5

Channel Geometry Coordinates		
Proposed	x (ft)	y (ft)
Fldpln LB	-40.00	17.80
Top LB	-4.50	1.25
Toe LB	-2.50	0.25
Thalweg	0.00	0.00
Toe RB	3.00	0.25
Top RB	4.50	1.25
Fldpln RB	12.00	3.80

Proposed Cross-Section and Structure Geometry (Looking D/S)

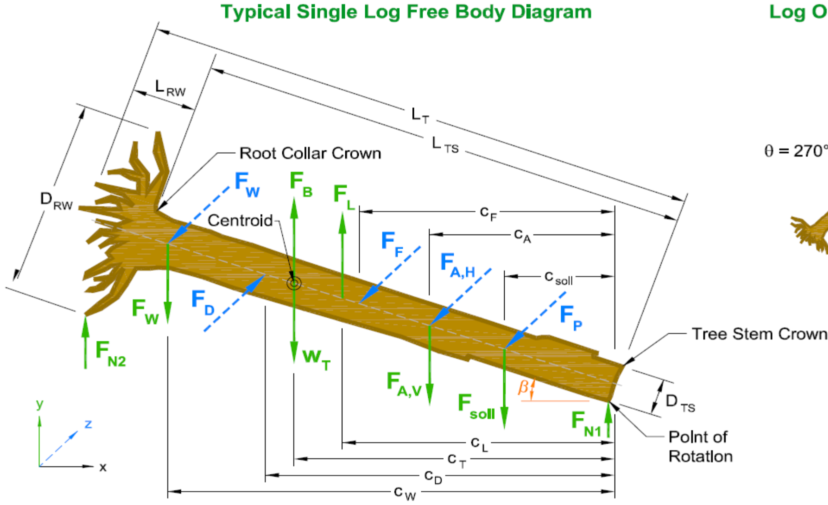


Wood Species	Rootwad	L_T (ft)	D_{TS} (ft)	L_{RW} (ft)	D_{RW} (ft)	γ_{Td} (lb/ft^3)	γ_{Tgr} (lb/ft^3)
Douglas-fir, Coast	No	20.0	1.00	-	-	33.5	38.0

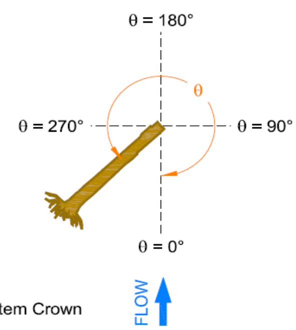
Structure Geometry	θ (deg)	β (deg)	Define Fixed Point	x_T (ft)	y_T (ft)	$y_{T,min}$ (ft)	$y_{T,max}$ (ft)	A_{Tp} (ft^2)
	165.0	8.0	Root collar: Bottom	-20.00	7.50	7.50	11.27	0.00

Soils	Material	γ_s (lb/ft^3)	γ'_s (lb/ft^3)	ϕ (deg)	Soil Class	$L_{T,em}$ (ft)	$d_{b,max}$ (ft)	$d_{b,avg}$ (ft)
Stream Bed	Very coarse gravel	128.3	79.9	40.0	5	0.00	0.00	0.00
Bank	Gravel/cobble	137.0	85.3	41.0	4	20.00	0.00	0.00

Typical Single Log Free Body Diagram



Log Orientation (Plan View)



Vertical Force Analysis

Net Buoyancy Force

Wood	V_{TS} (ft³)	V_{RW} (ft³)	V_T (ft³)	W_T (lbf)	F_B (lbf)
↑WSE	15.7	0.0	15.7	527	0
↓WS↑Thw	0.0	0.0	0.0	0	0
↓Thalweg	0.0	0.0	0.0	0	0
Total	15.7	0.0	15.7	527	0

Lift Force

C_{LT}	0.00
F_L (lbf)	0

Vertical Force Balance

F_B (lbf)	0
F_L (lbf)	0
W_T (lbf)	527
F_{soil} (lbf)	0
$F_{W,V}$ (lbf)	1,774
$F_{A,V}$ (lbf)	0
ΣF_V (lbf)	2,301
FS_V	#DIV/0!

#DIV/0!

Soil Ballast Force

Soil	V_{dry} (ft³)	V_{sat} (ft³)	V_{soil} (ft³)	F_{soil} (lbf)
Bed	0.0	0.0	0.0	0
Bank	0.0	0.0	0.0	0
Total	0.0	0.0	0.0	0

Horizontal Force Analysis

Drag Force

A_{Tp} / A_W	Fr_L	C_{Di}	C_w	C_D*	F_D (lbf)
0.00	0.85	0.62	0.00	0.61	0

Horizontal Force Balance

F_D (lbf)	0
F_P (lbf)	0
F_F (lbf)	1,994
$F_{W,H}$ (lbf)	0
$F_{A,H}$ (lbf)	0
ΣF_H (lbf)	1,994
FS_H	3,988.53

Passive Soil Pressure / Friction Force

Soil	K_P	F_P (lbf)	L_{Tf} (ft)	μ	F_F (lbf)
Bed	4.60	0	2.00	0.84	176
Bank	4.81	0	20.00	0.87	1,818
Total	-	0	22.00	-	1,994

Moment Force Balance

Driving Moment Centroids / Resisting Moment Centroids

$c_{T,B}$ (ft)	c_L (ft)	c_D (ft)	$c_{T,W}$ (ft)	c_{soil} (ft)	$c_{F\&N}$ (ft)	c_P (ft)
10.0	0.0	0.0	10.0	0.0	10.0	0.0

*Distances are from the stem tip

Point of Rotation: Root Collar

Moment Force Balance

M_d (lbf)	10
M_r (lbf)	74,099
FS_M	7,484.25

Anchor Forces

Additional Soil Ballast

V_{Adry} (ft³)	V_{Awet} (ft³)	c_{Asoil} (ft)	$F_{A,Vsoil}$ (lbf)	$F_{A,HP}$ (lbf)
			0	0

Mechanical Anchors

Type	c_{Am} (ft)	Soils	F_{Am} (lbf)
			0
			0

Boulder Ballast

Position	D_r (ft)	c_{Ar} (ft)	$V_{r,dry}$ (ft³)	$V_{r,wet}$ (ft³)	W_r (lbf)	$F_{L,r}$ (lbf)	$F_{D,r}$ (lbf)	$F_{A,Vr}$ (lbf)	$F_{A,Hr}$ (lbf)
								0	0
								0	0
								0	0

Interaction Forces with Adjacent Logs

Log ID	Position	Link	c_{WI} (ft)	$F_{W,V}$ (lbf)	$F_{W,H}$ (lbf)	Applied Forces from other Logs: $F_{W,V}$ (lbf)	Applied Forces from other Logs: $F_{W,H}$ (lbf)
A Log #2	Above	Gravity	5.0	-1,774	-1,367	1,774 ↓	0
						0	0
						0	0
						0	0

SR 8 MP 3.16 Unnamed Tributary to Wildcat Creek

Spreadsheet developed by
Michael Rafferty, P.E.

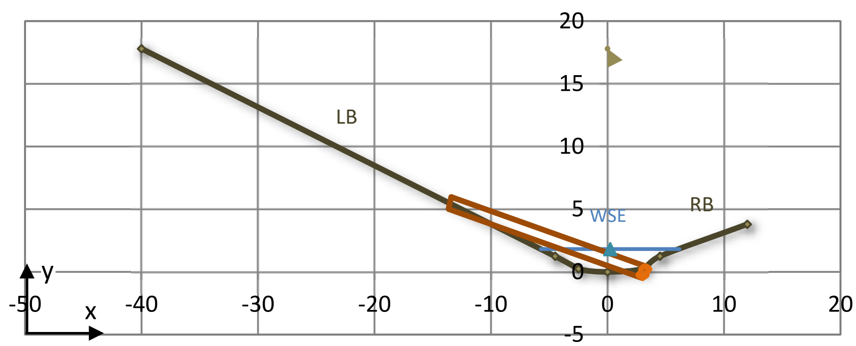
Single Log Stability Analysis Model Inputs

Site ID	Structure Type	Structure Position	Meander	Station	d_w (ft)	R_c/W_{BF}	u_{des} (ft/s)
Wildcat	Rootwad	Left bank	Straight	6+40	1.82	5.49	4.80

Multi-Log Structures	Layer	Log ID
	Stacked	A Log #6

Channel Geometry Coordinates		
Proposed	x (ft)	y (ft)
Fldpln LB	-40.00	17.80
Top LB	-4.50	1.25
Toe LB	-2.50	0.25
Thalweg	0.00	0.00
Toe RB	3.00	0.25
Top RB	4.50	1.25
Fldpln RB	12.00	3.80

Proposed Cross-Section and Structure Geometry (Looking D/S)

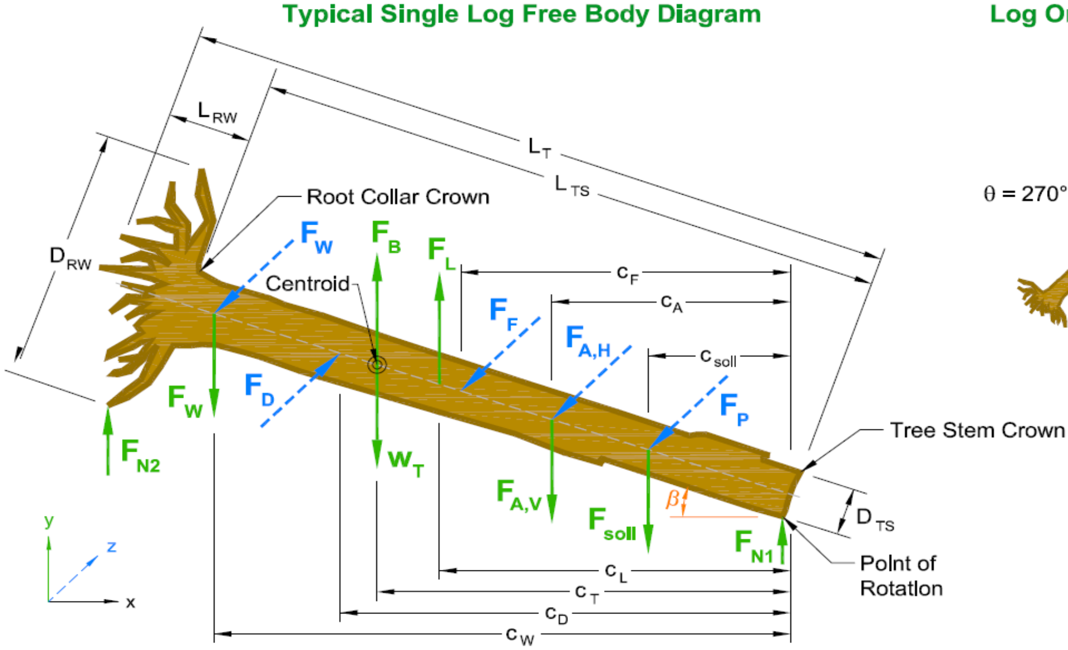


Wood Species	Rootwad	L_T (ft)	D_{TS} (ft)	L_{RW} (ft)	D_{RW} (ft)	γ_{Td} (lb/ft^3)	γ_{Tgr} (lb/ft^3)
Douglas-fir, Coast	No	20.0	1.00	-	-	33.5	38.0

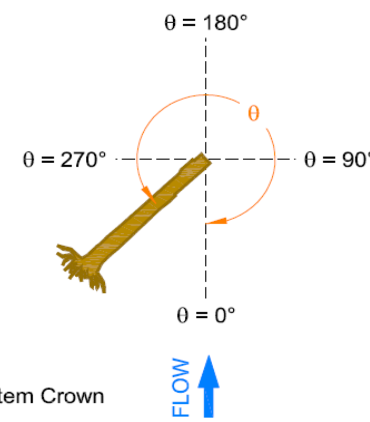
Structure Geometry	θ (deg)	β (deg)	Define Fixed Point	x_T (ft)	y_T (ft)	$y_{T,min}$ (ft)	$y_{T,max}$ (ft)	A_{Tp} (ft^2)
	120.0	16.0	Root collar: Bottom	3.00	-0.50	-0.50	5.97	4.96

Soils	Material	γ_s (lb/ft^3)	γ'_s (lb/ft^3)	φ (deg)	Soil Class	$L_{T,em}$ (ft)	$d_{b,max}$ (ft)	$d_{b,avg}$ (ft)
Stream Bed	Very coarse gravel	128.3	79.9	40.0	5	0.00	0.00	0.00
Bank	Gravel/cobble	137.0	85.3	41.0	4	0.00	0.00	0.00

Typical Single Log Free Body Diagram



Log Orientation (Plan View)



Vertical Force Analysis

Net Buoyancy Force

Wood	V_{TS} (ft^3)	V_{RW} (ft^3)	V_T (ft^3)	W_T (lbf)	F_B (lbf)
↑WSE	10.5	0.0	10.5	351	0
↓WS↑Thw	4.9	0.0	4.9	165	307
↓Thalweg	0.3	0.0	0.3	12	20
Total	15.7	0.0	15.7	528	327

Lift Force

C_{LT}	0.00
F_L (lbf)	0

Vertical Force Balance

F_B (lbf)	327 ↑
F_L (lbf)	0
W_T (lbf)	528 ↓
F_{soil} (lbf)	0
$F_{W,V}$ (lbf)	1,774 ↓
$F_{A,V}$ (lbf)	0
ΣF_V (lbf)	1,975 ↓
FS_V	7.04 ✓

Soil Ballast Force

Soil	V_{dry} (ft^3)	V_{sat} (ft^3)	V_{soil} (ft^3)	F_{soil} (lbf)
Bed	0.0	0.0	0.0	0
Bank	0.0	0.0	0.0	0
Total	0.0	0.0	0.0	0

Horizontal Force Analysis

Drag Force

A_{Tp} / A_W	Fr_L	C_{Di}	C_w	C_D*	F_D (lbf)
0.33	0.85	1.02	0.38	3.17	351

Horizontal Force Balance

F_D (lbf)	351 →
F_P (lbf)	0
F_F (lbf)	1,686 ←
$F_{W,H}$ (lbf)	0
$F_{A,H}$ (lbf)	0
ΣF_H (lbf)	1,335 ←
FS_H	4.80 ✓

Passive Soil Pressure / Friction Force

Soil	K_P	F_P (lbf)	L_{Tf} (ft)	µ	F_F (lbf)
Bed	4.60	0	4.00	0.84	861
Bank	4.81	0	3.70	0.87	825
Total	-	0	7.70	-	1,686

Moment Force Balance

Driving Moment Centroids / Resisting Moment Centroids

$c_{T,B}$ (ft)	c_L (ft)	c_D (ft)	$c_{T,W}$ (ft)	c_{soil} (ft)	$c_{F\&N}$ (ft)	c_P (ft)
10.0	0.0	15.8	10.0	0.0	8.5	0.0

*Distances are from the stem tip

Point of Rotation: Root Collar

Moment Force Balance

M_d (lbf)	4,562
M_r (lbf)	71,061
FS_M	15.58 ✓

Anchor Forces

Additional Soil Ballast

V_{Adry} (ft^3)	V_{Awet} (ft^3)	c_{Asoil} (ft)	$F_{A,Vsoil}$ (lbf)	$F_{A,HP}$ (lbf)
			0	0

Mechanical Anchors

Type	c_{Am} (ft)	Soils	F_{Am} (lbf)
			0
			0

Boulder Ballast

Position	D_r (ft)	c_{Ar} (ft)	$V_{r,dry}$ (ft^3)	$V_{r,wet}$ (ft^3)	W_r (lbf)	$F_{L,r}$ (lbf)	$F_{D,r}$ (lbf)	$F_{A,Vr}$ (lbf)	$F_{A,Hr}$ (lbf)
								0	0
								0	0
								0	0

Wildcat Rootwad Stacked Log ID A Log #6 Page 3

Interaction Forces with Adjacent Logs

						Applied Forces from other Logs	
Log ID	Position	Link	c_{WI} (ft)	$F_{W,V}$ (lbf)	$F_{W,H}$ (lbf)	$F_{W,V}$ (lbf)	$F_{W,H}$ (lbf)
A Log #2	Above	Gravity	5.0	-1,774	-1,367	1,774	0
						0	0
						0	0
						0	0

SR 8 MP 3.16 Unnamed Tributary to Wildcat Creek

Spreadsheet developed by
Michael Rafferty, P.E.

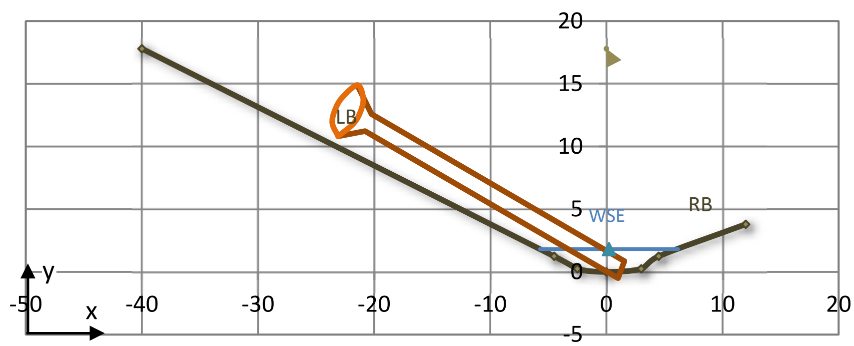
Single Log Stability Analysis Model Inputs

Site ID	Structure Type	Structure Position	Meander	Station	d_w (ft)	R_c/W_{BF}	u_{des} (ft/s)
Wildcat	Rootwad	Left bank	Straight	6+40	1.82	5.49	4.80

Multi-Log Structures	Layer	Log ID
	Stacked	B Log #1

Channel Geometry Coordinates		
Proposed	x (ft)	y (ft)
Fldpln LB	-40.00	17.80
Top LB	-4.50	1.25
Toe LB	-2.50	0.25
Thalweg	0.00	0.00
Toe RB	3.00	0.25
Top RB	4.50	1.25
Fldpln RB	12.00	3.80

Proposed Cross-Section and Structure Geometry (Looking D/S)

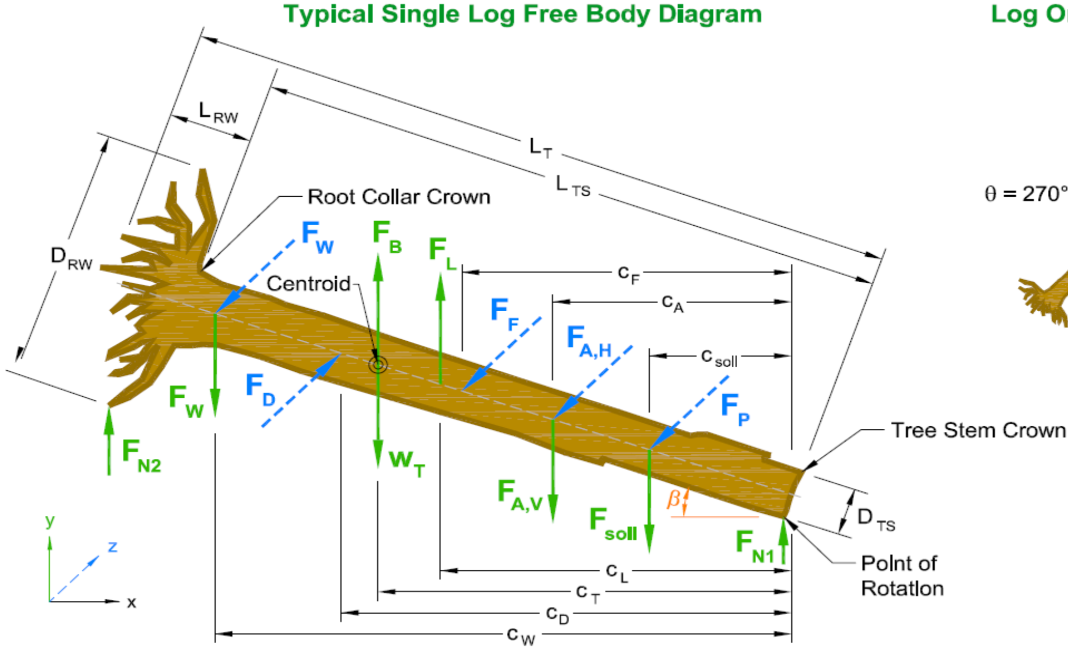


Wood Species	Rootwad	L_T (ft)	D_{TS} (ft)	L_{RW} (ft)	D_{RW} (ft)	γ_{Td} (lb/ft^3)	γ_{Tgr} (lb/ft^3)
Douglas-fir, Coast	Yes	30.0	1.50	2.25	4.50	33.5	38.0

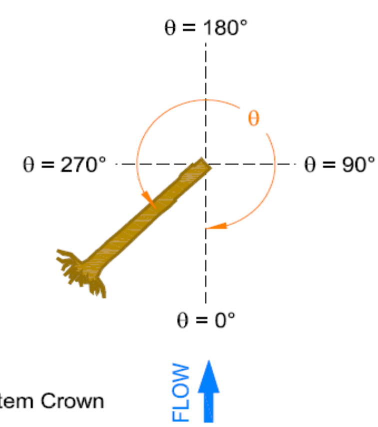
Structure Geometry	θ (deg)	β (deg)	Define Fixed Point	x_T (ft)	y_T (ft)	$y_{T,min}$ (ft)	$y_{T,max}$ (ft)	A_{Tp} (ft^2)
	300.0	-25.0	Stem tip: Bottom	1.00	-0.50	-0.50	14.90	4.65

Soils	Material	γ_s (lb/ft^3)	γ'_s (lb/ft^3)	ϕ (deg)	Soil Class	$L_{T,em}$ (ft)	$d_{b,max}$ (ft)	$d_{b,avg}$ (ft)
Stream Bed	Very coarse gravel	128.3	79.9	40.0	5	0.00	0.00	0.00
Bank	Gravel/cobble	137.0	85.3	41.0	4	0.00	0.00	0.00

Typical Single Log Free Body Diagram



Log Orientation (Plan View)



Vertical Force Analysis

Net Buoyancy Force

Wood	V_{TS} (ft^3)	V_{RW} (ft^3)	V_T (ft^3)	W_T (lbf)	F_B (lbf)
↑WSE	42.2	13.8	56.0	1,877	0
↓WS↑Thw	6.6	0.0	6.6	220	410
↓Thalweg	0.3	0.0	0.3	11	18
Total	49.0	13.8	62.8	2,109	428

Lift Force

C_{LT}	0.00
F_L (lbf)	0

Vertical Force Balance

F_B (lbf)	428
F_L (lbf)	0
W_T (lbf)	2,109
F_{soil} (lbf)	0
$F_{W,V}$ (lbf)	96
$F_{A,V}$ (lbf)	0
ΣF_V (lbf)	1,585
FS_V	4.02

Soil Ballast Force

Soil	V_{dry} (ft^3)	V_{sat} (ft^3)	V_{soil} (ft^3)	F_{soil} (lbf)
Bed	0.0	0.0	0.0	0
Bank	0.0	0.0	0.0	0
Total	0.0	0.0	0.0	0

Horizontal Force Analysis

Drag Force

A_{Tp} / A_W	Fr_L	C_{Di}	C_w	C_D*	F_D (lbf)
0.31	0.69	1.02	0.43	3.09	321

Horizontal Force Balance

F_D (lbf)	321
F_P (lbf)	0
F_F (lbf)	1,330
$F_{W,H}$ (lbf)	0
$F_{A,H}$ (lbf)	0
ΣF_H (lbf)	1,009
FS_H	4.14

Passive Soil Pressure / Friction Force

Soil	K_P	F_P (lbf)	L_{Tf} (ft)	μ	F_F (lbf)
Bed	4.60	0	3.28	0.84	1,330
Bank	4.81	0	0.00	0.87	0
Total	-	0	3.28	-	1,330

Moment Force Balance

Driving Moment Centroids / Resisting Moment Centroids

$c_{T,B}$ (ft)	c_L (ft)	c_D (ft)	$c_{T,W}$ (ft)	c_{soil} (ft)	$c_{F\&N}$ (ft)	c_P (ft)
17.2	0.0	2.7	17.2	0.0	0.6	0.0

*Distances are from the stem tip

Point of Rotation: Rootwad

Moment Force Balance

M_d (lbf)	15,068
M_r (lbf)	102,042
FS_M	6.77

Anchor Forces

Additional Soil Ballast

V_{Adry} (ft^3)	V_{Awet} (ft^3)	c_{Asoil} (ft)	$F_{A,Vsoil}$ (lbf)	$F_{A,HP}$ (lbf)
			0	0

Mechanical Anchors

Type	c_{Am} (ft)	Soils	F_{Am} (lbf)
			0
			0

Boulder Ballast

Position	D_r (ft)	c_{Ar} (ft)	$V_{r,dry}$ (ft^3)	$V_{r,wet}$ (ft^3)	W_r (lbf)	$F_{L,r}$ (lbf)	$F_{D,r}$ (lbf)	$F_{A,Vr}$ (lbf)	$F_{A,Hr}$ (lbf)
								0	0
								0	0
								0	0

Wildcat Rootwad Stacked Log ID B Log #1

Interaction Forces with Adjacent Logs

Applied Forces from other Logs

Log ID	Position	Link	c_{WI} (ft)	$F_{W,V}$ (lbf)	$F_{W,H}$ (lbf)	$F_{W,V}$ (lbf)	$F_{W,H}$ (lbf)
B Log #5	Below	Gravity	5.0	96	105	96 ↑	0
						0	0
						0	0
						0	0

SR 8 MP 3.16 Unnamed Tributary to Wildcat Creek

Spreadsheet developed by
Michael Rafferty, P.E.

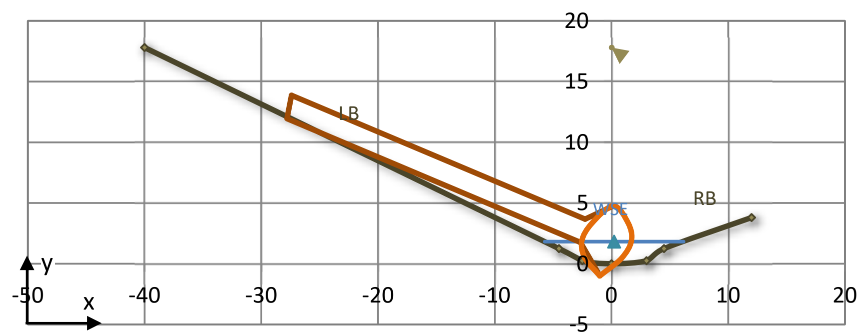
Single Log Stability Analysis Model Inputs

Site ID	Structure Type	Structure Position	Meander	Station	d_w (ft)	R_c/W_{BF}	u_{des} (ft/s)
Wildcat	Rootwad	Left bank	Straight	6+40	1.82	5.49	4.80

Multi-Log Structures	Layer	Log ID
	Stacked	B Log #2

Channel Geometry Coordinates		
Proposed	x (ft)	y (ft)
Fldpln LB	-40.00	17.80
Top LB	-4.50	1.25
Toe LB	-2.50	0.25
Thalweg	0.00	0.00
Toe RB	3.00	0.25
Top RB	4.50	1.25
Fldpln RB	12.00	3.80

Proposed Cross-Section and Structure Geometry (Looking D/S)

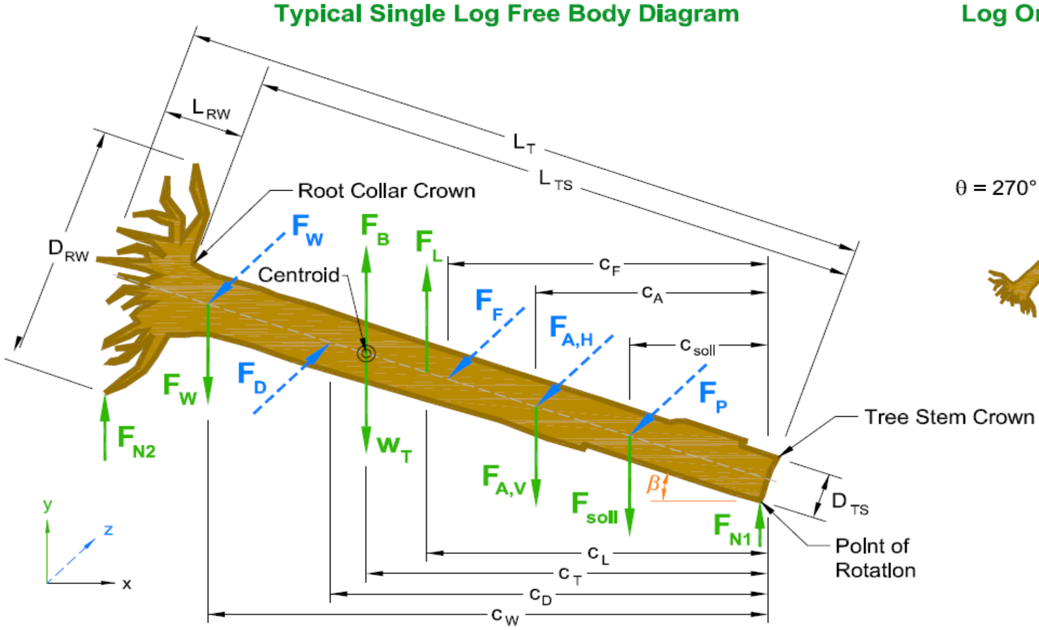


Wood Species	Rootwad	L_T (ft)	D_{TS} (ft)	L_{RW} (ft)	D_{RW} (ft)	γ_{Td} (lb/ft^3)	γ_{Tgr} (lb/ft^3)
Douglas-fir, Coast	Yes	40.0	2.00	3.00	6.00	33.5	38.0

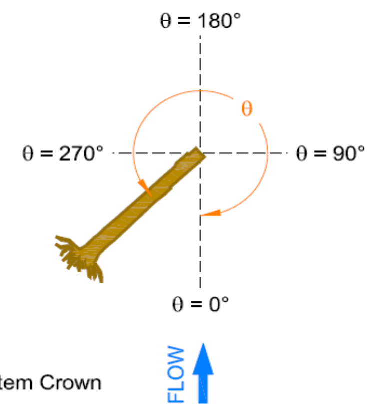
Structure Geometry	θ (deg)	β (deg)	Define Fixed Point	x_T (ft)	y_T (ft)	$y_{T,min}$ (ft)	$y_{T,max}$ (ft)	A_{Tp} (ft^2)
	45.0	16.0	Rootwad: Bottom	-1.00	-1.00	-1.00	13.87	64.60

Soils	Material	γ_s (lb/ft^3)	γ'_s (lb/ft^3)	ϕ (deg)	Soil Class	$L_{T,em}$ (ft)	$d_{b,max}$ (ft)	$d_{b,avg}$ (ft)
Stream Bed	Very coarse gravel	128.3	79.9	40.0	5	0.00	0.00	0.00
Bank	Gravel/cobble	137.0	85.3	41.0	4	0.00	0.00	0.00

Typical Single Log Free Body Diagram



Log Orientation (Plan View)



Vertical Force Analysis

Net Buoyancy Force

Wood	V_{TS} (ft³)	V_{RW} (ft³)	V_T (ft³)	W_T (lbf)	F_B (lbf)
↑WSE	116.2	18.5	134.7	4,518	0
↓WS↑Thw	0.0	13.2	13.2	444	825
↓Thalweg	0.0	1.0	1.0	38	62
Total	116.2	32.7	148.9	5,000	887

Lift Force

C_{LT}	0.00
F_L (lbf)	0

Vertical Force Balance

F_B (lbf)	887	↑
F_L (lbf)	0	
W_T (lbf)	5,000	↓
F_{soil} (lbf)	0	
$F_{W,V}$ (lbf)	0	
$F_{A,V}$ (lbf)	0	
ΣF_V (lbf)	4,113	↓
FS_V	5.64	✓

Soil Ballast Force

Soil	V_{dry} (ft³)	V_{sat} (ft³)	V_{soil} (ft³)	F_{soil} (lbf)
Bed	0.0	0.0	0.0	0
Bank	0.0	0.0	0.0	0
Total	0.0	0.0	0.0	0

Horizontal Force Analysis

Drag Force

A_{Tp} / A_W	Fr_L	C_{Di}	C_w	C_D*	F_D (lbf)
4.29	0.60	1.12	0.00	#NUM!	#NUM!

Horizontal Force Balance

F_D (lbf)	#NUM!	
F_P (lbf)	0	
F_F (lbf)	3,451	←
$F_{W,H}$ (lbf)	0	
$F_{A,H}$ (lbf)	0	
ΣF_H (lbf)	#NUM!	
FS_H	#NUM!	#NUM!

Passive Soil Pressure / Friction Force

Soil	K_P	F_P (lbf)	L_{Tf} (ft)	μ	F_F (lbf)
Bed	4.60	0	2.00	0.84	3,451
Bank	4.81	0	0.00	0.87	0
Total	-	0	2.00	-	3,451

Moment Force Balance

Driving Moment Centroids / Resisting Moment Centroids

$c_{T,B}$ (ft)	c_L (ft)	c_D (ft)	$c_{T,W}$ (ft)	c_{soil} (ft)	$c_{F\&N}$ (ft)	c_P (ft)
23.0	0.0	#NUM!	23.0	0.0	0.0	0.0

*Distances are from the stem tip

Point of Rotation: Rootwad

Moment Force Balance

M_d (lbf)	#NUM!	
M_r (lbf)	372,515	
FS_M	#NUM!	#NUM!

Anchor Forces

Additional Soil Ballast

V_{Adry} (ft³)	V_{Awet} (ft³)	c_{Asoil} (ft)	$F_{A,Vsoil}$ (lbf)	$F_{A,HP}$ (lbf)
			0	0

Mechanical Anchors

Type	c_{Am} (ft)	Soils	F_{Am} (lbf)
			0
			0

Boulder Ballast

Position	D_r (ft)	c_{Ar} (ft)	$V_{r,dry}$ (ft³)	$V_{r,wet}$ (ft³)	W_r (lbf)	$F_{L,r}$ (lbf)	$F_{D,r}$ (lbf)	$F_{A,Vr}$ (lbf)	$F_{A,Hr}$ (lbf)
								0	0
								0	0
								0	0

Interaction Forces with Adjacent Logs

						Applied Forces from other Logs	
Log ID	Position	Link	c_{WI} (ft)	$F_{W,V}$ (lbf)	$F_{W,H}$ (lbf)	$F_{W,V}$ (lbf)	$F_{W,H}$ (lbf)
B Log #6	Below	Gravity	30.0	-130	218	0	0
						0	0
						0	0
						0	0

SR 8 MP 3.16 Unnamed Tributary to Wildcat Creek

Spreadsheet developed by
Michael Rafferty, P.E.

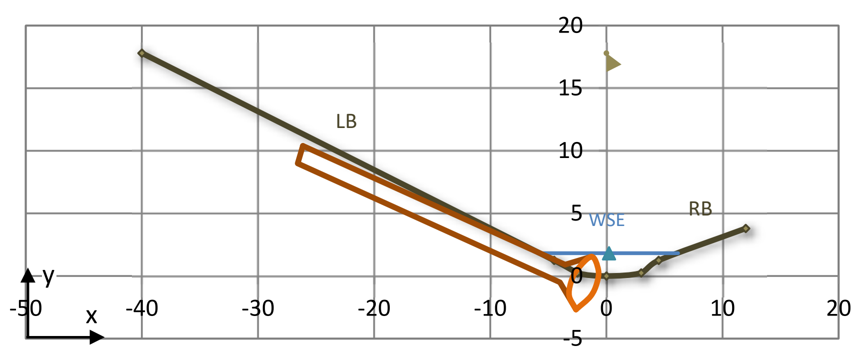
Single Log Stability Analysis Model Inputs

Site ID	Structure Type	Structure Position	Meander	Station	d_w (ft)	R_c/W_{BF}	u_{des} (ft/s)
Wildcat	Rootwad	Left bank	Straight	6+40	1.82	5.49	4.80

Multi-Log Structures	Layer	Log ID
	Stacked	B Log #3

Channel Geometry Coordinates		
Proposed	x (ft)	y (ft)
Fldpln LB	-40.00	17.80
Top LB	-4.50	1.25
Toe LB	-2.50	0.25
Thalweg	0.00	0.00
Toe RB	3.00	0.25
Top RB	4.50	1.25
Fldpln RB	12.00	3.80

Proposed Cross-Section and Structure Geometry (Looking D/S)

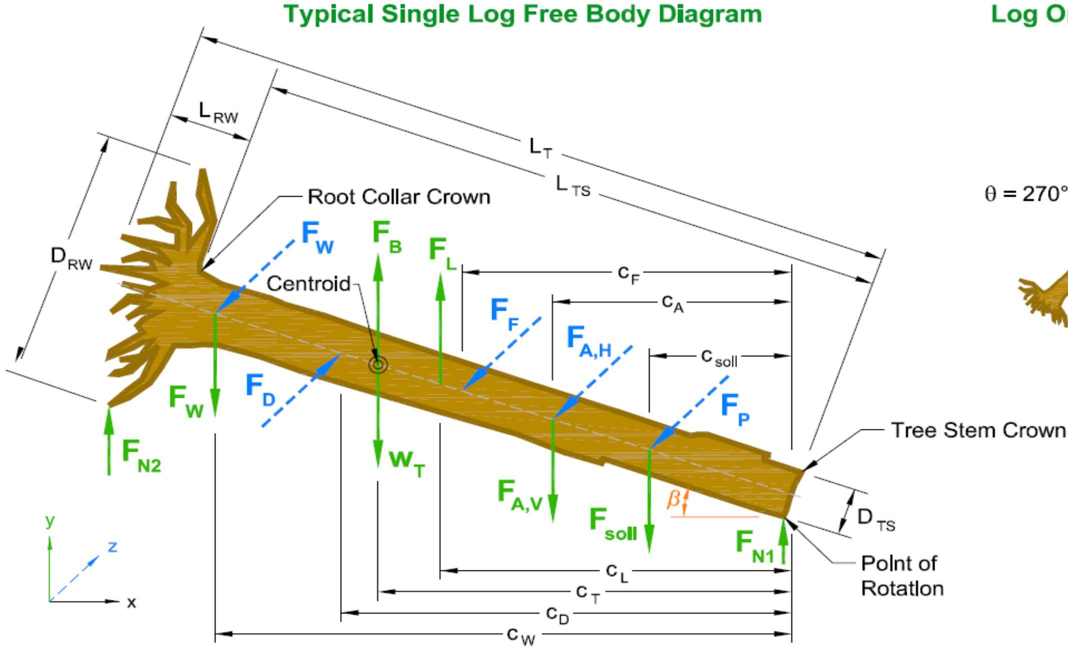


Wood Species	Rootwad	L_T (ft)	D_{TS} (ft)	L_{RW} (ft)	D_{RW} (ft)	γ_{Td} (lb/ft^3)	γ_{Tgr} (lb/ft^3)
Douglas-fir, Coast	Yes	30.0	1.50	2.25	4.50	33.5	38.0

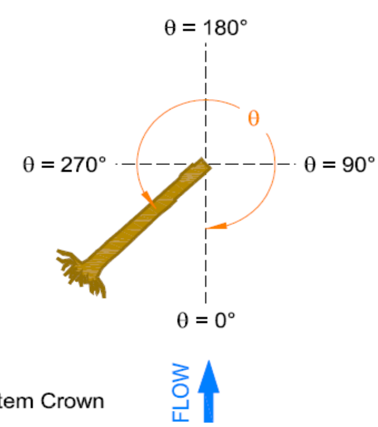
Structure Geometry	θ (deg)	β (deg)	Define Fixed Point	x_T (ft)	y_T (ft)	$y_{T,min}$ (ft)	$y_{T,max}$ (ft)	A_{Tp} (ft^2)
	120.0	20.0	Root collar: Bottom	-4.00	-0.50	-2.68	10.40	3.78

Soils	Material	γ_s (lb/ft^3)	γ'_s (lb/ft^3)	ϕ (deg)	Soil Class	$L_{T,em}$ (ft)	$d_{b,max}$ (ft)	$d_{b,avg}$ (ft)
Stream Bed	Very coarse gravel	128.3	79.9	40.0	5	0.83	0.03	0.03
Bank	Gravel/cobble	137.0	85.3	41.0	4	25.08	0.94	0.47

Typical Single Log Free Body Diagram



Log Orientation (Plan View)



Vertical Force Analysis

Net Buoyancy Force

Wood	V_{TS} (ft^3)	V_{RW} (ft^3)	V_T (ft^3)	W_T (lbf)	F_B (lbf)
↑WSE	40.7	0.0	40.7	1,365	0
↓WS↑Thw	8.0	6.7	14.7	493	916
↓Thalweg	0.3	7.1	7.4	283	465
Total	49.0	13.8	62.8	2,141	1,381

Lift Force

C_{LT}	0.00
F_L (lbf)	0

Vertical Force Balance

F_B (lbf)	1,381
F_L (lbf)	0
W_T (lbf)	2,141
F_{soil} (lbf)	2,416
$F_{W,V}$ (lbf)	0
$F_{A,V}$ (lbf)	0
ΣF_V (lbf)	3,175
FS_V	3.30

Soil Ballast Force

Soil	V_{dry} (ft^3)	V_{sat} (ft^3)	V_{soil} (ft^3)	F_{soil} (lbf)
Bed	0.0	0.0	0.0	0
Bank	17.6	0.0	17.6	2,415
Total	17.6	0.0	17.6	2,416

Horizontal Force Analysis

Drag Force

A_{Tp} / A_W	Fr_L	C_{Di}	C_w	C_D*	F_D (lbf)
0.25	0.69	0.94	0.43	2.47	209

Horizontal Force Balance

F_D (lbf)	209
F_P (lbf)	5,815
F_F (lbf)	2,751
$F_{W,H}$ (lbf)	0
$F_{A,H}$ (lbf)	0
ΣF_H (lbf)	8,358
FS_H	40.96

Passive Soil Pressure / Friction Force

Soil	K_P	F_P (lbf)	L_{Tf} (ft)	μ	F_F (lbf)
Bed	4.60	1	2.98	0.84	248
Bank	4.81	5,815	29.02	0.87	2,504
Total	-	5,815	32.00	-	2,751

Moment Force Balance

Driving Moment Centroids / Resisting Moment Centroids

$c_{T,B}$ (ft)	c_L (ft)	c_D (ft)	$c_{T,W}$ (ft)	c_{soil} (ft)	$c_{F\&N}$ (ft)	c_P (ft)
17.4	0.0	27.5	17.4	12.6	15.0	15.0

*Distances are from the stem tip

Point of Rotation:	Rootwad

Moment Force Balance

M_d (lbf)	16,814
M_r (lbf)	230,254
FS_M	13.69

Anchor Forces

Additional Soil Ballast

V_{Adry} (ft^3)	V_{Awet} (ft^3)	c_{Asoil} (ft)	$F_{A,Vsoil}$ (lbf)	$F_{A,HP}$ (lbf)
			0	0

Mechanical Anchors

Type	c_{Am} (ft)	Soils	F_{Am} (lbf)
			0
			0

Boulder Ballast

Position	D_r (ft)	c_{Ar} (ft)	$V_{r,dry}$ (ft^3)	$V_{r,wet}$ (ft^3)	W_r (lbf)	$F_{L,r}$ (lbf)	$F_{D,r}$ (lbf)	$F_{A,Vr}$ (lbf)	$F_{A,Hr}$ (lbf)
								0	0
								0	0
								0	0

SR 8 MP 3.16 Unnamed Tributary to Wildcat Creek

Spreadsheet developed by
Michael Rafferty, P.E.

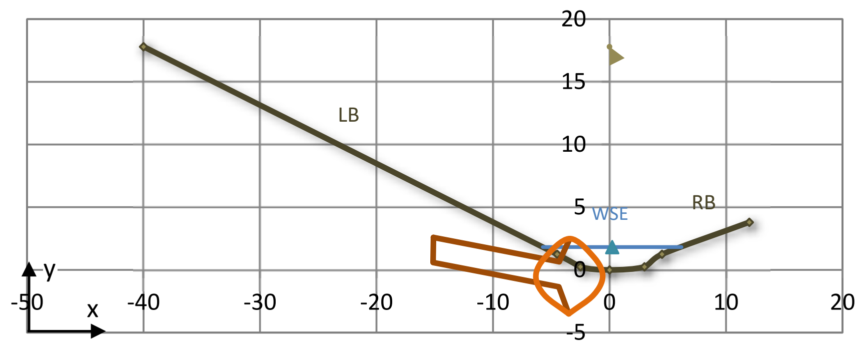
Single Log Stability Analysis Model Inputs

Site ID	Structure Type	Structure Position	Meander	Station	d_w (ft)	R_c/W_{BF}	u_{des} (ft/s)
Wildcat	Rootwad	Left bank	Straight	6+40	1.82	5.49	4.80

Multi-Log Structures	Layer	Log ID
	Key Log	B Log #4

Channel Geometry Coordinates		
Proposed	x (ft)	y (ft)
Fldpln LB	-40.00	17.80
Top LB	-4.50	1.25
Toe LB	-2.50	0.25
Thalweg	0.00	0.00
Toe RB	3.00	0.25
Top RB	4.50	1.25
Fldpln RB	12.00	3.80

Proposed Cross-Section and Structure Geometry (Looking D/S)

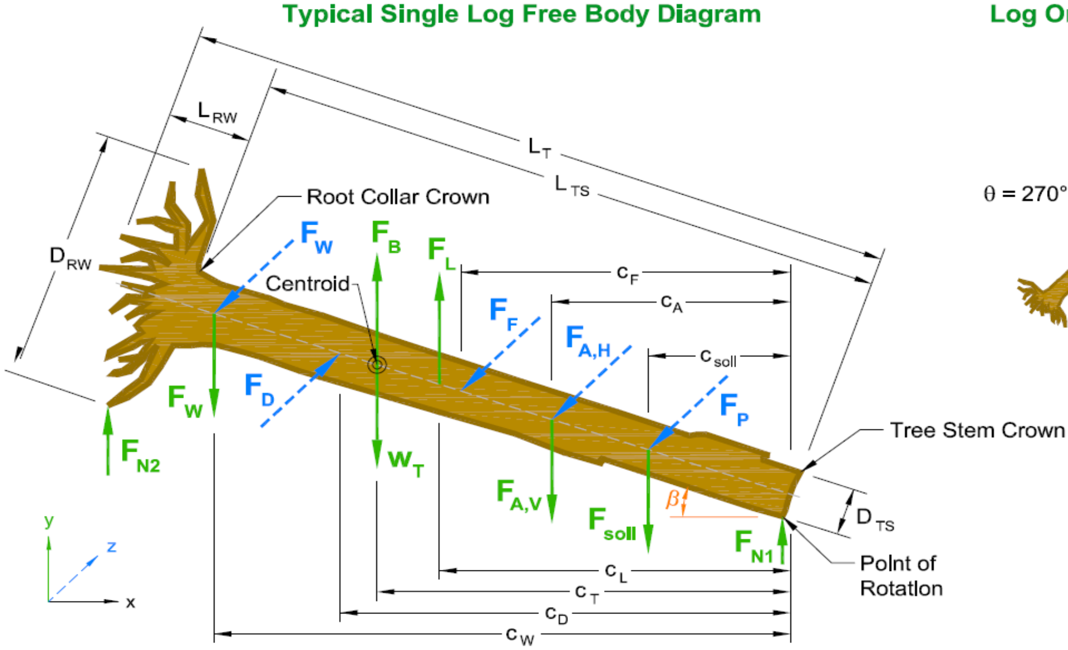


Wood Species	Rootwad	L_T (ft)	D_{TS} (ft)	L_{RW} (ft)	D_{RW} (ft)	γ_{Td} (lb/ft^3)	γ_{Tgr} (lb/ft^3)
Douglas-fir, Coast	Yes	40.0	2.00	3.00	6.00	33.5	38.0

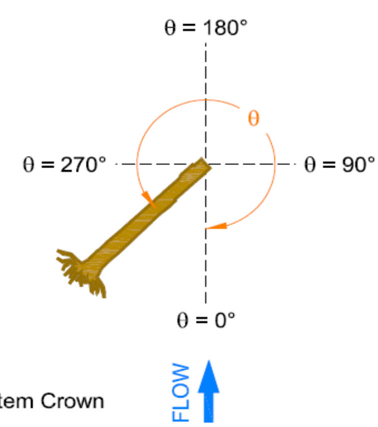
Structure Geometry	θ (deg)	β (deg)	Define Fixed Point	x_T (ft)	y_T (ft)	$y_{T,min}$ (ft)	$y_{T,max}$ (ft)	A_{Tp} (ft^2)
	17.0	3.0	Rootwad: Bottom	-3.50	-3.50	-3.50	2.59	9.00

Soils	Material	γ_s (lb/ft^3)	γ'_s (lb/ft^3)	ϕ (deg)	Soil Class	$L_{T,em}$ (ft)	$d_{b,max}$ (ft)	$d_{b,avg}$ (ft)
Stream Bed	Very coarse gravel	128.3	79.9	40.0	5	0.00	0.00	0.00
Bank	Gravel/cobble	137.0	85.3	41.0	4	40.00	3.61	1.93

Typical Single Log Free Body Diagram



Log Orientation (Plan View)



Vertical Force Analysis

Net Buoyancy Force

Wood	V_{TS} (ft^3)	V_{RW} (ft^3)	V_T (ft^3)	W_T (lbf)	F_B (lbf)
↑WSE	6.8	0.6	7.4	249	0
↓WS↑Thw	84.0	11.6	95.6	3,207	5,966
↓Thalweg	25.4	20.5	45.9	1,743	2,862
Total	116.2	32.7	148.9	5,200	8,828

Lift Force

C_{LT}	0.00
F_L (lbf)	0

Vertical Force Balance

F_B (lbf)	8,828	↑
F_L (lbf)	0	
W_T (lbf)	5,200	↓
F_{soil} (lbf)	19,906	↓
$F_{W,V}$ (lbf)	0	
$F_{A,V}$ (lbf)	0	
ΣF_V (lbf)	16,278	↓
FS_V	2.84	✓

Soil Ballast Force

Soil	V_{dry} (ft^3)	V_{sat} (ft^3)	V_{soil} (ft^3)	F_{soil} (lbf)
Bed	0.0	0.0	0.0	0
Bank	129.7	25.1	154.8	19,906
Total	129.7	25.1	154.8	19,906

Horizontal Force Analysis

Drag Force

A_{Tp} / A_W	Fr_L	C_{Di}	C_w	C_D*	F_D (lbf)
0.60	0.60	1.24	0.00	8.07	1,624

Passive Soil Pressure / Friction Force

Soil	K_P	F_P (lbf)	L_{Tf} (ft)	μ	F_F (lbf)
Bed	4.60	0	2.00	0.84	650
Bank	4.81	47,924	40.00	0.87	13,476
Total	-	47,924	42.00	-	14,127

Horizontal Force Balance

F_D (lbf)	1,624	→
F_P (lbf)	47,924	←
F_F (lbf)	14,127	←
$F_{W,H}$ (lbf)	0	
$F_{A,H}$ (lbf)	0	
ΣF_H (lbf)	60,427	←
FS_H	38.20	✓

Moment Force Balance

Driving Moment Centroids / Resisting Moment Centroids

$c_{T,B}$ (ft)	c_L (ft)	c_D (ft)	$c_{T,W}$ (ft)	c_{soil} (ft)	$c_{F\&N}$ (ft)	c_P (ft)
23.2	0.0	0.0	23.2	20.0	20.0	20.0

*Distances are from the stem tip

Point of Rotation: Rootwad

Moment Force Balance

M_d (lbf)	213,240
M_r (lbf)	2,049,397
FS_M	9.61 ✓

Anchor Forces

Additional Soil Ballast

V_{Adry} (ft^3)	V_{Awet} (ft^3)	c_{Asoil} (ft)	$F_{A,Vsoil}$ (lbf)	$F_{A,HP}$ (lbf)
			0	0

Mechanical Anchors

Type	c_{Am} (ft)	Soils	F_{Am} (lbf)
			0
			0

Boulder Ballast

Position	D_r (ft)	c_{Ar} (ft)	$V_{r,dry}$ (ft^3)	$V_{r,wet}$ (ft^3)	W_r (lbf)	$F_{L,r}$ (lbf)	$F_{D,r}$ (lbf)	$F_{A,Vr}$ (lbf)	$F_{A,Hr}$ (lbf)
								0	0
								0	0
								0	0

SR 8 MP 3.16 Unnamed Tributary to Wildcat Creek

Spreadsheet developed by
Michael Rafferty, P.E.

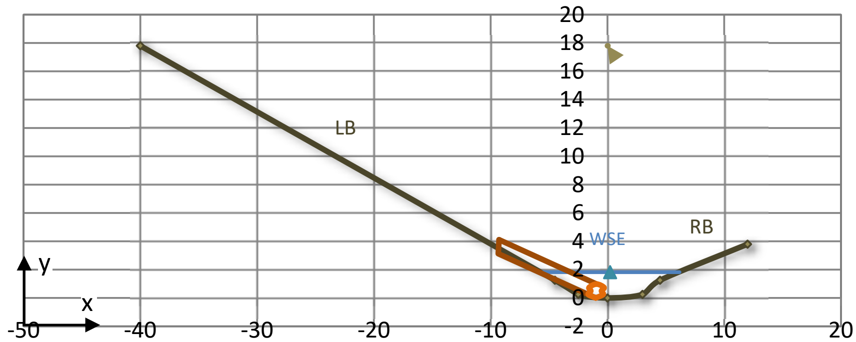
Single Log Stability Analysis Model Inputs

Site ID	Structure Type	Structure Position	Meander	Station	d_w (ft)	R_c/W_{BF}	u_{des} (ft/s)
Wildcat	Rootwad	Left bank	Straight	6+40	1.82	5.49	4.80

Multi-Log Structures	Layer	Log ID
	Stacked	B Log #5

Channel Geometry Coordinates		
Proposed	x (ft)	y (ft)
Fldpln LB	-40.00	17.80
Top LB	-4.50	1.25
Toe LB	-2.50	0.25
Thalweg	0.00	0.00
Toe RB	3.00	0.25
Top RB	4.50	1.25
Fldpln RB	12.00	3.80

Proposed Cross-Section and Structure Geometry (Looking D/S)

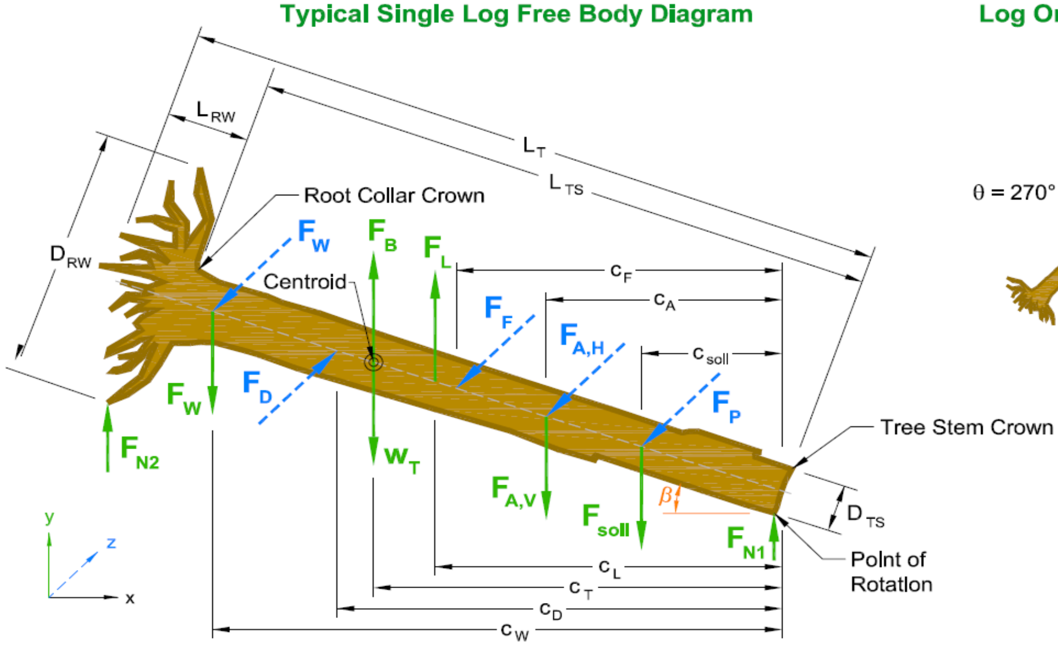


Wood Species	Rootwad	L_T (ft)	D_{TS} (ft)	L_{RW} (ft)	D_{RW} (ft)	γ_{Td} (lb/ft^3)	γ_{Tgr} (lb/ft^3)
Douglas-fir, Coast	No	20.0	1.00	-	-	33.5	38.0

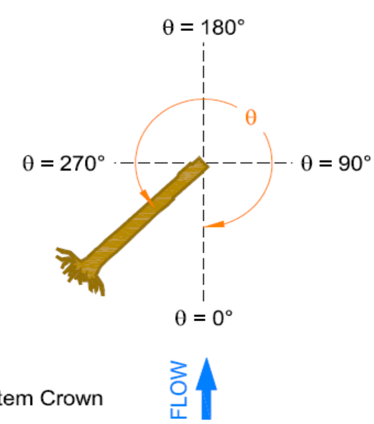
Structure Geometry	θ (deg)	β (deg)	Define Fixed Point	x_T (ft)	y_T (ft)	$y_{T,min}$ (ft)	$y_{T,max}$ (ft)	A_{Tp} (ft^2)
	25.0	9.0	Root collar: Bottom	-1.00	0.00	0.00	4.12	3.55

Soils	Material	γ_s (lb/ft^3)	γ'_s (lb/ft^3)	ϕ (deg)	Soil Class	$L_{T,em}$ (ft)	$d_{b,max}$ (ft)	$d_{b,avg}$ (ft)
Stream Bed	Very coarse gravel	128.3	79.9	40.0	5	0.00	0.00	0.00
Bank	Gravel/cobble	137.0	85.3	41.0	4	0.00	0.00	0.00

Typical Single Log Free Body Diagram



Log Orientation (Plan View)



Vertical Force Analysis

Net Buoyancy Force

Wood	V_{TS} (ft^3)	V_{RW} (ft^3)	V_T (ft^3)	W_T (lbf)	F_B (lbf)
↑WSE	9.0	0.0	9.0	304	0
↓WS↑Thw	6.7	0.0	6.7	223	415
↓Thalweg	0.0	0.0	0.0	0	0
Total	15.7	0.0	15.7	527	415

Lift Force

C_{LT}	0.00
F_L (lbf)	0

Vertical Force Balance

F_B (lbf)	415	↑
F_L (lbf)	0	
W_T (lbf)	527	↓
F_{soil} (lbf)	0	
$F_{W,V}$ (lbf)	734	↓
$F_{A,V}$ (lbf)	0	
ΣF_V (lbf)	845	↓
FS_V	3.03	✓

Soil Ballast Force

Soil	V_{dry} (ft^3)	V_{sat} (ft^3)	V_{soil} (ft^3)	F_{soil} (lbf)
Bed	0.0	0.0	0.0	0
Bank	0.0	0.0	0.0	0
Total	0.0	0.0	0.0	0

Horizontal Force Analysis

Drag Force

A_{Tp} / A_W	Fr_L	C_{Di}	C_w	C_D*	F_D (lbf)
0.24	0.85	0.54	0.43	1.69	134

Horizontal Force Balance

F_D (lbf)	134	→
F_P (lbf)	0	
F_F (lbf)	728	←
$F_{W,H}$ (lbf)	0	
$F_{A,H}$ (lbf)	0	
ΣF_H (lbf)	594	←
FS_H	5.43	✓

Passive Soil Pressure / Friction Force

Soil	K_P	F_P (lbf)	L_{Tf} (ft)	μ	F_F (lbf)
Bed	4.60	0	2.85	0.84	168
Bank	4.81	0	9.15	0.87	560
Total	-	0	12.00	-	728

Moment Force Balance

Driving Moment Centroids / Resisting Moment Centroids

$c_{T,B}$ (ft)	c_L (ft)	c_D (ft)	$c_{T,W}$ (ft)	c_{soil} (ft)	$c_{F\&N}$ (ft)	c_P (ft)
10.0	0.0	14.2	10.0	0.0	5.9	0.0

*Distances are from the stem tip

Point of Rotation: Root Collar

Moment Force Balance

M_d (lbf)	4,872
M_r (lbf)	37,998
FS_M	7.80 ✓

Anchor Forces

Additional Soil Ballast

V_{Adry} (ft^3)	V_{Awet} (ft^3)	c_{Asoil} (ft)	$F_{A,Vsoil}$ (lbf)	$F_{A,HP}$ (lbf)
			0	0

Mechanical Anchors

Type	c_{Am} (ft)	Soils	F_{Am} (lbf)
			0
			0

Boulder Ballast

Position	D_r (ft)	c_{Ar} (ft)	$V_{r,dry}$ (ft^3)	$V_{r,wet}$ (ft^3)	W_r (lbf)	$F_{L,r}$ (lbf)	$F_{D,r}$ (lbf)	$F_{A,Vr}$ (lbf)	$F_{A,Hr}$ (lbf)
								0	0
								0	0
								0	0

Interaction Forces with Adjacent Logs

Applied Forces from other Logs

Log ID	Position	Link	c_{WI} (ft)	$F_{W,V}$ (lbf)	$F_{W,H}$ (lbf)	$F_{W,V}$ (lbf)	$F_{W,H}$ (lbf)
B Log #1	Above	Gravity	5.0	-734	-465	734	0
						0	0
						0	0
						0	0

SR 8 MP 3.16 Unnamed Tributary to Wildcat Creek

Spreadsheet developed by Michael Rafferty, P.E.

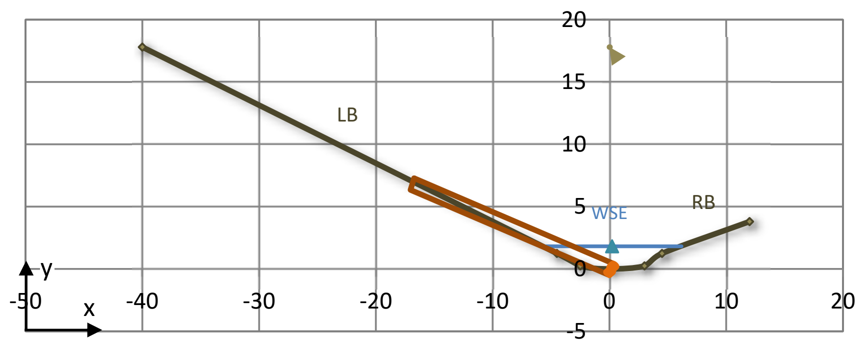
Single Log Stability Analysis Model Inputs

Site ID	Structure Type	Structure Position	Meander	Station	d_w (ft)	R_c/W_{BF}	u_{des} (ft/s)
Wildcat	Rootwad	Left bank	Straight	6+40	1.82	5.49	4.80

Multi-Log Structures	Layer	Log ID
	Stacked	B Log #6

Channel Geometry Coordinates		
Proposed	x (ft)	y (ft)
Fldpln LB	-40.00	17.80
Top LB	-4.50	1.25
Toe LB	-2.50	0.25
Thalweg	0.00	0.00
Toe RB	3.00	0.25
Top RB	4.50	1.25
Fldpln RB	12.00	3.80

Proposed Cross-Section and Structure Geometry (Looking D/S)

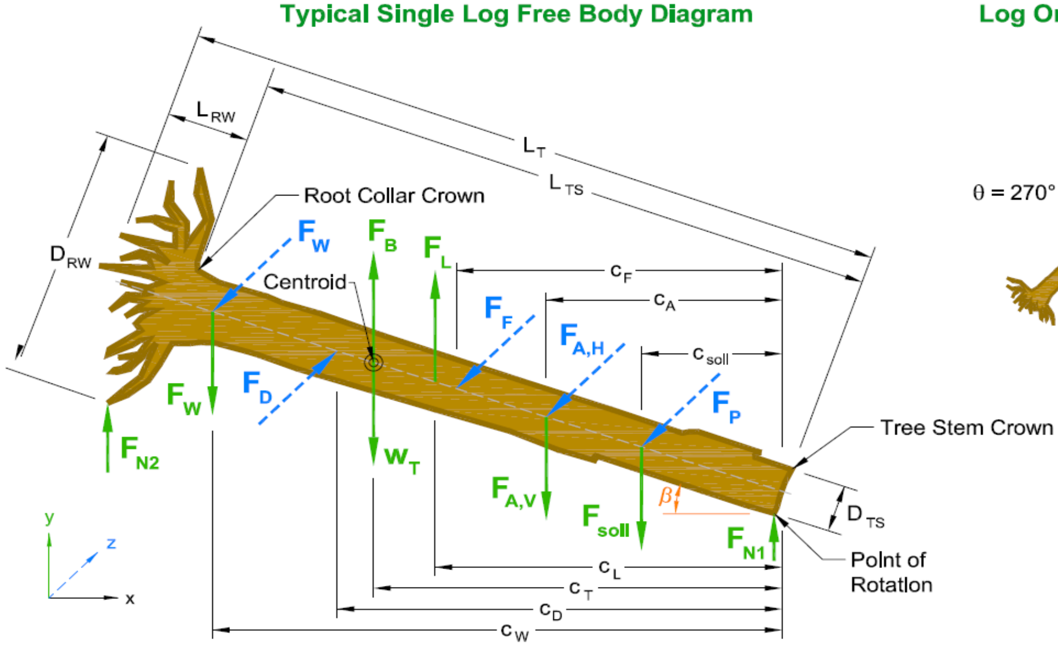


Wood Species	Rootwad	L_T (ft)	D_{TS} (ft)	L_{RW} (ft)	D_{RW} (ft)	γ_{Td} (lb/ft^3)	γ_{Tgr} (lb/ft^3)
Douglas-fir, Coast	No	20.0	1.00	-	-	33.5	38.0

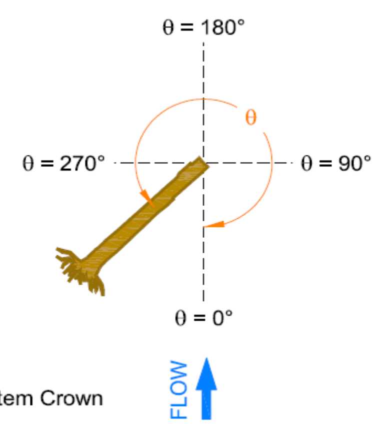
Structure Geometry	θ (deg)	β (deg)	Define Fixed Point	x_T (ft)	y_T (ft)	$y_{T,min}$ (ft)	$y_{T,max}$ (ft)	A_{Tp} (ft^2)
	115.0	20.0	Root collar: Bottom	0.00	-0.50	-0.50	7.28	4.45

Soils	Material	γ_s (lb/ft^3)	γ'_s (lb/ft^3)	ϕ (deg)	Soil Class	$L_{T,em}$ (ft)	$d_{b,max}$ (ft)	$d_{b,avg}$ (ft)
Stream Bed	Very coarse gravel	128.3	79.9	40.0	5	0.00	0.00	0.00
Bank	Gravel/cobble	137.0	85.3	41.0	4	0.00	0.00	0.00

Typical Single Log Free Body Diagram



Log Orientation (Plan View)



Vertical Force Analysis

Net Buoyancy Force

Wood	V_{TS} (ft^3)	V_{RW} (ft^3)	V_T (ft^3)	W_T (lbf)	F_B (lbf)
↑WSE	11.5	0.0	11.5	384	0
↓WS↑Thw	4.0	0.0	4.0	134	249
↓Thalweg	0.3	0.0	0.3	10	17
Total	15.7	0.0	15.7	528	265

Lift Force

C_{LT}	0.00
F_L (lbf)	0

Vertical Force Balance

F_B (lbf)	265
F_L (lbf)	0
W_T (lbf)	528
F_{soil} (lbf)	0
$F_{W,V}$ (lbf)	3,669
$F_{A,V}$ (lbf)	0
ΣF_V (lbf)	3,932
FS_V	15.83

Soil Ballast Force

Soil	V_{dry} (ft^3)	V_{sat} (ft^3)	V_{soil} (ft^3)	F_{soil} (lbf)
Bed	0.0	0.0	0.0	0
Bank	0.0	0.0	0.0	0
Total	0.0	0.0	0.0	0

Horizontal Force Analysis

Drag Force

A_{Tp} / A_W	Fr_L	C_{Di}	C_w	C_D*	F_D (lbf)
0.30	0.85	1.08	0.37	2.98	297

Horizontal Force Balance

F_D (lbf)	297
F_P (lbf)	0
F_F (lbf)	3,387
$F_{W,H}$ (lbf)	0
$F_{A,H}$ (lbf)	0
ΣF_H (lbf)	3,091
FS_H	11.42

Passive Soil Pressure / Friction Force

Soil	K_P	F_P (lbf)	L_{Tf} (ft)	μ	F_F (lbf)
Bed	4.60	0	3.85	0.84	853
Bank	4.81	0	11.05	0.87	2,535
Total	-	0	14.90	-	3,387

Moment Force Balance

Driving Moment Centroids / Resisting Moment Centroids

$c_{T,B}$ (ft)	c_L (ft)	c_D (ft)	$c_{T,W}$ (ft)	c_{soil} (ft)	$c_{F\&N}$ (ft)	c_P (ft)
10.0	0.0	16.7	10.0	0.0	7.5	0.0

*Distances are from the stem tip

Point of Rotation: Root Collar

Moment Force Balance

M_d (lbf)	3,425
M_r (lbf)	142,738
FS_M	41.68

Anchor Forces

Additional Soil Ballast

V_{Adry} (ft^3)	V_{Awet} (ft^3)	c_{Asoil} (ft)	$F_{A,Vsoil}$ (lbf)	$F_{A,HP}$ (lbf)
			0	0

Mechanical Anchors

Type	c_{Am} (ft)	Soils	F_{Am} (lbf)
			0
			0

Boulder Ballast

Position	D_r (ft)	c_{Ar} (ft)	$V_{r,dry}$ (ft^3)	$V_{r,wet}$ (ft^3)	W_r (lbf)	$F_{L,r}$ (lbf)	$F_{D,r}$ (lbf)	$F_{A,Vr}$ (lbf)	$F_{A,Hr}$ (lbf)
								0	0
								0	0
								0	0

Interaction Forces with Adjacent Logs

						Applied Forces from other Logs		
Log ID	Position	Link	c_{WI} (ft)	$F_{W,V}$ (lbf)	$F_{W,H}$ (lbf)	$F_{W,V}$ (lbf)		$F_{W,H}$ (lbf)
B Log #2	Above	Gravity	5.0	-3,669	0	3,669	↓	0
						0		0
						0		0
						0		0

SR 8 MP 3.16 Unnamed Tributary to Wildcat Creek

Spreadsheet developed by
Michael Rafferty, P.E.

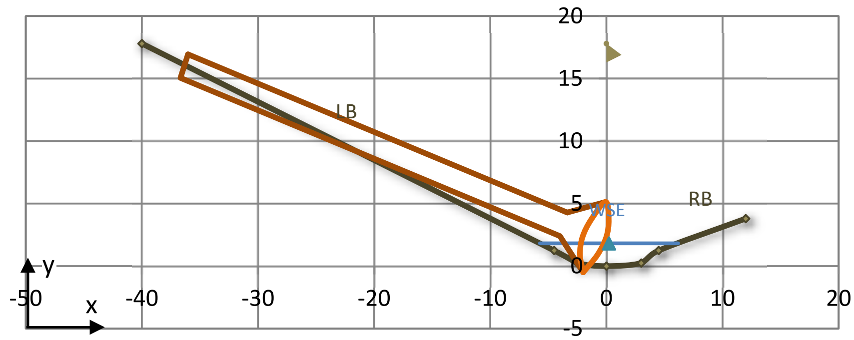
Single Log Stability Analysis Model Inputs

Site ID	Structure Type	Structure Position	Meander	Station	d_w (ft)	R_c/W_{BF}	u_{des} (ft/s)
Wildcat	Rootwad	Left bank	Straight	6+40	1.82	5.49	4.80

Multi-Log Structures	Layer	Log ID
	Stacked	D Log #1

Channel Geometry Coordinates		
Proposed	x (ft)	y (ft)
Fldpln LB	-40.00	17.80
Top LB	-4.50	1.25
Toe LB	-2.50	0.25
Thalweg	0.00	0.00
Toe RB	3.00	0.25
Top RB	4.50	1.25
Fldpln RB	12.00	3.80

Proposed Cross-Section and Structure Geometry (Looking D/S)

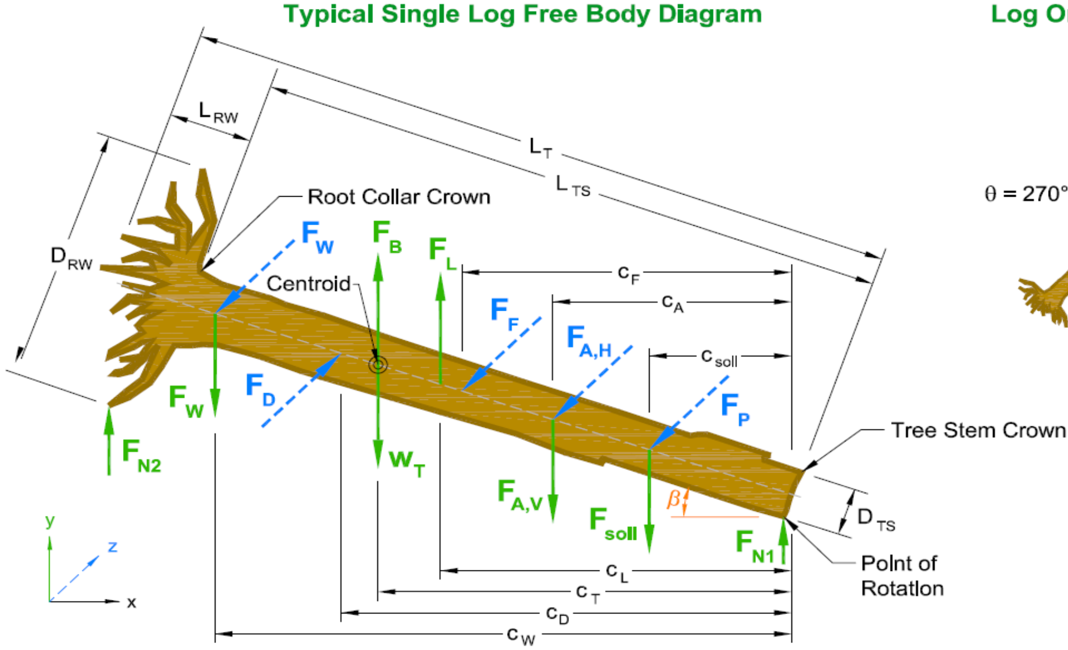


Wood Species	Rootwad	L_T (ft)	D_{TS} (ft)	L_{RW} (ft)	D_{RW} (ft)	γ_{Td} (lb/ft^3)	γ_{Tgr} (lb/ft^3)
Douglas-fir, Coast	Yes	40.0	2.00	3.00	6.00	33.5	38.0

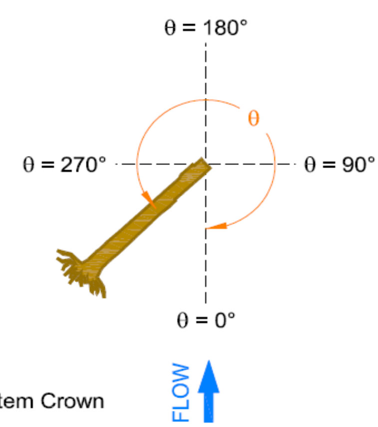
Structure Geometry	θ (deg)	β (deg)	Define Fixed Point	x_T (ft)	y_T (ft)	$y_{T,min}$ (ft)	$y_{T,max}$ (ft)	A_{Tp} (ft^2)
	110.0	20.0	Rootwad: Bottom	-2.00	-0.50	-0.50	16.94	78.97

Soils	Material	γ_s (lb/ft^3)	γ'_s (lb/ft^3)	ϕ (deg)	Soil Class	$L_{T,em}$ (ft)	$d_{b,max}$ (ft)	$d_{b,avg}$ (ft)
Stream Bed	Very coarse gravel	128.3	79.9	40.0	5	0.00	0.00	0.00
Bank	Gravel/cobble	137.0	85.3	41.0	4	0.00	0.00	0.00

Typical Single Log Free Body Diagram



Log Orientation (Plan View)



Vertical Force Analysis

Net Buoyancy Force

Wood	V_{TS} (ft^3)	V_{RW} (ft^3)	V_T (ft^3)	W_T (lbf)	F_B (lbf)
↑WSE	116.2	21.8	138.1	4,631	0
↓WS↑Thw	0.0	10.7	10.7	359	667
↓Thalweg	0.0	0.2	0.2	6	10
Total	116.2	32.7	148.9	4,996	678

Lift Force

C_{LT}	0.00
F_L (lbf)	0

Vertical Force Balance

F_B (lbf)	678
F_L (lbf)	0
W_T (lbf)	4,996
F_{soil} (lbf)	0
$F_{W,V}$ (lbf)	0
$F_{A,V}$ (lbf)	0
ΣF_V (lbf)	4,318
FS_V	7.37

Soil Ballast Force

Soil	V_{dry} (ft^3)	V_{sat} (ft^3)	V_{soil} (ft^3)	F_{soil} (lbf)
Bed	0.0	0.0	0.0	0
Bank	0.0	0.0	0.0	0
Total	0.0	0.0	0.0	0

Horizontal Force Analysis

Drag Force

A_{Tp} / A_W	Fr_L	C_{Di}	C_w	C_D*	F_D (lbf)
5.25	0.60	1.00	0.00	#NUM!	#NUM!

Horizontal Force Balance

F_D (lbf)	#NUM!
F_P (lbf)	0
F_F (lbf)	3,736
$F_{W,H}$ (lbf)	0
$F_{A,H}$ (lbf)	0
ΣF_H (lbf)	#NUM!
FS_H	#NUM!

#NUM!

Passive Soil Pressure / Friction Force

Soil	K_P	F_P (lbf)	L_{Tf} (ft)	μ	F_F (lbf)
Bed	4.60	0	2.00	0.84	486
Bank	4.81	0	12.90	0.87	3,250
Total	-	0	14.90	-	3,736

Moment Force Balance

Driving Moment Centroids / Resisting Moment Centroids

$c_{T,B}$ (ft)	c_L (ft)	c_D (ft)	$c_{T,W}$ (ft)	c_{soil} (ft)	$c_{F\&N}$ (ft)	c_P (ft)
23.0	0.0	#NUM!	23.0	0.0	6.4	0.0

*Distances are from the stem tip

Point of Rotation: Rootwad

Moment Force Balance

M_d (lbf)	#NUM!
M_r (lbf)	334,173
FS_M	#NUM!

#NUM!

Anchor Forces

Additional Soil Ballast

V_{Adry} (ft^3)	V_{Awet} (ft^3)	c_{Asoil} (ft)	$F_{A,Vsoil}$ (lbf)	$F_{A,HP}$ (lbf)
			0	0

Mechanical Anchors

Type	c_{Am} (ft)	Soils	F_{Am} (lbf)
			0
			0

Boulder Ballast

Position	D_r (ft)	c_{Ar} (ft)	$V_{r,dry}$ (ft^3)	$V_{r,wet}$ (ft^3)	W_r (lbf)	$F_{L,r}$ (lbf)	$F_{D,r}$ (lbf)	$F_{A,Vr}$ (lbf)	$F_{A,Hr}$ (lbf)
								0	0
								0	0
								0	0

Interaction Forces with Adjacent Logs

Log ID	Position	Link	c_{WI} (ft)	$F_{W,V}$ (lbf)	$F_{W,H}$ (lbf)	Applied Forces from other Logs: $F_{W,V}$ (lbf)	Applied Forces from other Logs: $F_{W,H}$ (lbf)
D Log #2	Below	Gravity	24.0	-2,008	0	0	0
D Log #4	Below	Gravity	30.0	-256	-241	0	0
						0	0
						0	0

SR 8 MP 3.16 Unnamed Tributary to Wildcat Creek

Spreadsheet developed by
Michael Rafferty, P.E.

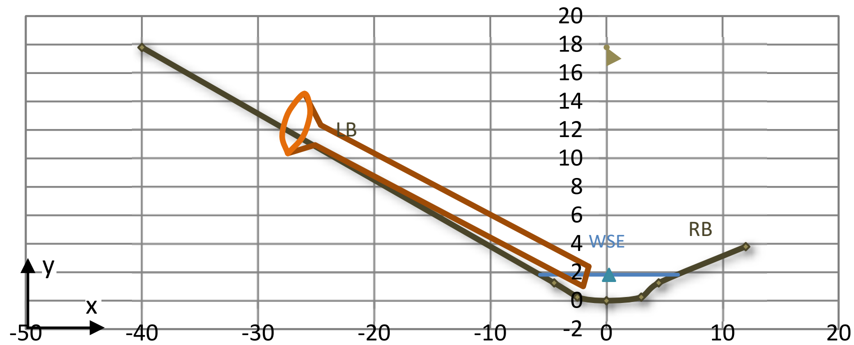
Single Log Stability Analysis Model Inputs

Site ID	Structure Type	Structure Position	Meander	Station	d_w (ft)	R_c/W_{BF}	u_{des} (ft/s)
Wildcat	Rootwad	Left bank	Straight	6+40	1.82	5.49	4.80

Multi-Log Structures	Layer	Log ID
	Stacked	D Log #2

Channel Geometry Coordinates		
Proposed	x (ft)	y (ft)
Fldpln LB	-40.00	17.80
Top LB	-4.50	1.25
Toe LB	-2.50	0.25
Thalweg	0.00	0.00
Toe RB	3.00	0.25
Top RB	4.50	1.25
Fldpln RB	12.00	3.80

Proposed Cross-Section and Structure Geometry (Looking D/S)

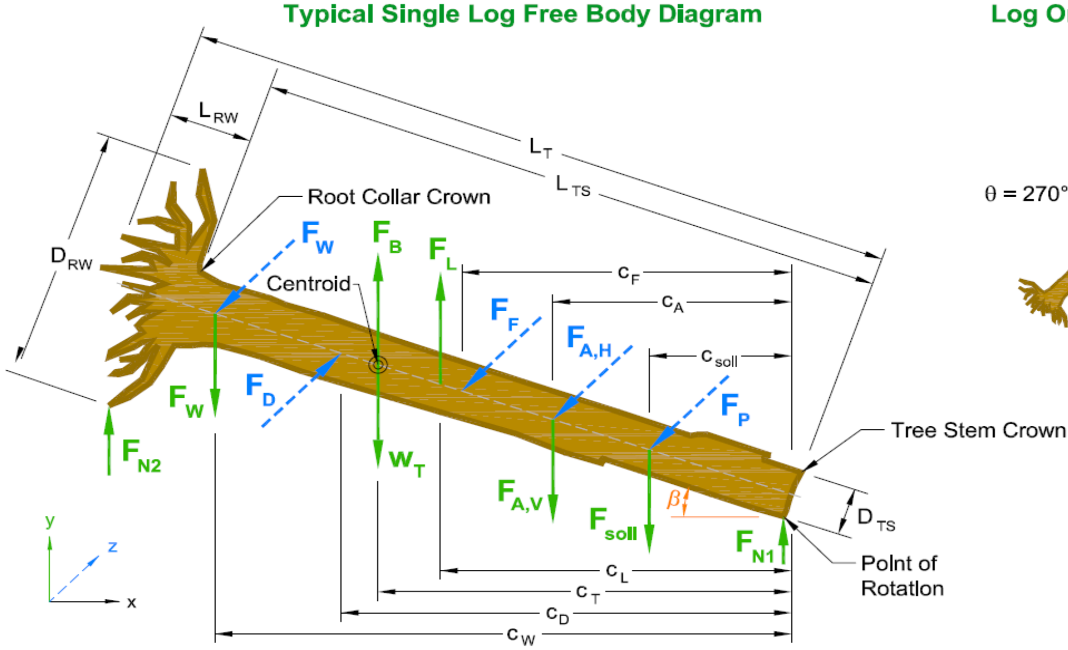


Wood Species	Rootwad	L_T (ft)	D_{TS} (ft)	L_{RW} (ft)	D_{RW} (ft)	γ_{Td} (lb/ft^3)	γ_{Tgr} (lb/ft^3)
Douglas-fir, Coast	Yes	30.0	1.50	2.25	4.50	33.5	38.0

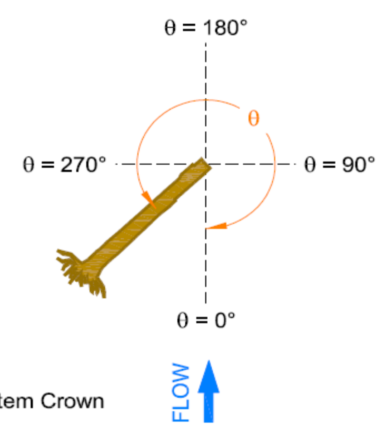
Structure Geometry	θ (deg)	β (deg)	Define Fixed Point	x_T (ft)	y_T (ft)	$y_{T,min}$ (ft)	$y_{T,max}$ (ft)	A_{Tp} (ft^2)
	243.0	-21.0	Stem tip: Bottom	-2.00	1.00	1.00	14.55	40.10

Soils	Material	γ_s (lb/ft^3)	γ'_s (lb/ft^3)	ϕ (deg)	Soil Class	$L_{T,em}$ (ft)	$d_{b,max}$ (ft)	$d_{b,avg}$ (ft)
Stream Bed	Very coarse gravel	128.3	79.9	40.0	5	0.00	0.00	0.00
Bank	Gravel/cobble	137.0	85.3	41.0	4	0.00	0.00	0.00

Typical Single Log Free Body Diagram



Log Orientation (Plan View)



Vertical Force Analysis

Net Buoyancy Force

Wood	V_{TS} (ft^3)	V_{RW} (ft^3)	V_T (ft^3)	W_T (lbf)	F_B (lbf)
↑WSE	48.0	13.8	61.8	2,072	0
↓WS↑Thw	1.1	0.0	1.1	36	66
↓Thalweg	0.0	0.0	0.0	0	0
Total	49.0	13.8	62.8	2,107	66

Lift Force

C_{LT}	0.00
F_L (lbf)	0

Vertical Force Balance

F_B (lbf)	66
F_L (lbf)	0
W_T (lbf)	2,107
F_{soil} (lbf)	0
$F_{W,V}$ (lbf)	1,990
$F_{A,V}$ (lbf)	0
ΣF_V (lbf)	4,031
FS_V	61.87

Soil Ballast Force

Soil	V_{dry} (ft^3)	V_{sat} (ft^3)	V_{soil} (ft^3)	F_{soil} (lbf)
Bed	0.0	0.0	0.0	0
Bank	0.0	0.0	0.0	0
Total	0.0	0.0	0.0	0

Horizontal Force Analysis

Drag Force

A_{Tp} / A_W	Fr_L	C_{Di}	C_w	C_D*	F_D (lbf)
2.66	0.69	1.06	0.00	#NUM!	#NUM!

Horizontal Force Balance

F_D (lbf)	#NUM!
F_P (lbf)	0
F_F (lbf)	3,383
$F_{W,H}$ (lbf)	0
$F_{A,H}$ (lbf)	0
ΣF_H (lbf)	#NUM!
FS_H	#NUM!

#NUM!

Passive Soil Pressure / Friction Force

Soil	K_P	F_P (lbf)	L_{Tf} (ft)	μ	F_F (lbf)
Bed	4.60	0	2.00	0.84	3,383
Bank	4.81	0	0.00	0.87	0
Total	-	0	2.00	-	3,383

Moment Force Balance

Driving Moment Centroids / Resisting Moment Centroids

$c_{T,B}$ (ft)	c_L (ft)	c_D (ft)	$c_{T,W}$ (ft)	c_{soil} (ft)	$c_{F\&N}$ (ft)	c_P (ft)
17.2	0.0	#NUM!	17.2	0.0	30.0	0.0

*Distances are from the stem tip

Point of Rotation: Rootwad

Moment Force Balance

M_d (lbf)	#NUM!
M_r (lbf)	65,973
FS_M	#NUM!

#NUM!

Anchor Forces

Additional Soil Ballast

V_{Adry} (ft^3)	V_{Awet} (ft^3)	c_{Asoil} (ft)	$F_{A,Vsoil}$ (lbf)	$F_{A,HP}$ (lbf)
			0	0

Mechanical Anchors

Type	c_{Am} (ft)	Soils	F_{Am} (lbf)
			0
			0

Boulder Ballast

Position	D_r (ft)	c_{Ar} (ft)	$V_{r,dry}$ (ft^3)	$V_{r,wet}$ (ft^3)	W_r (lbf)	$F_{L,r}$ (lbf)	$F_{D,r}$ (lbf)	$F_{A,Vr}$ (lbf)	$F_{A,Hr}$ (lbf)
								0	0
								0	0
								0	0

Interaction Forces with Adjacent Logs

Log ID	Position	Link	c_{WI} (ft)	$F_{W,V}$ (lbf)	$F_{W,H}$ (lbf)
D Log #1	Above	Gravity	8.0	-1,990	0
D Log #3	Below	Gravity	15.0	-164	177

Applied Forces from other Logs

$F_{W,V}$ (lbf)		$F_{W,H}$ (lbf)
1,990	↓	0
0		0
0		0
0		0

SR 8 MP 3.16 Unnamed Tributary to Wildcat Creek

Spreadsheet developed by
Michael Rafferty, P.E.

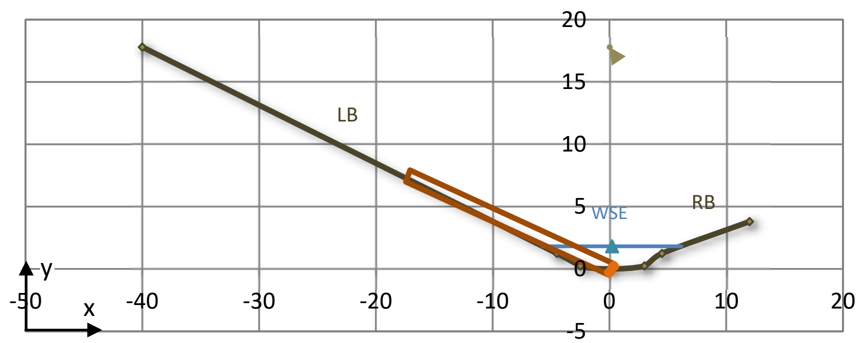
Single Log Stability Analysis Model Inputs

Site ID	Structure Type	Structure Position	Meander	Station	d_w (ft)	R_c/W_{BF}	u_{des} (ft/s)
Wildcat	Rootwad	Left bank	Straight	6+40	1.82	5.49	4.80

Multi-Log Structures	Layer	Log ID
	Stacked	D Log #3

Channel Geometry Coordinates		
Proposed	x (ft)	y (ft)
Fldpln LB	-40.00	17.80
Top LB	-4.50	1.25
Toe LB	-2.50	0.25
Thalweg	0.00	0.00
Toe RB	3.00	0.25
Top RB	4.50	1.25
Fldpln RB	12.00	3.80

Proposed Cross-Section and Structure Geometry (Looking D/S)

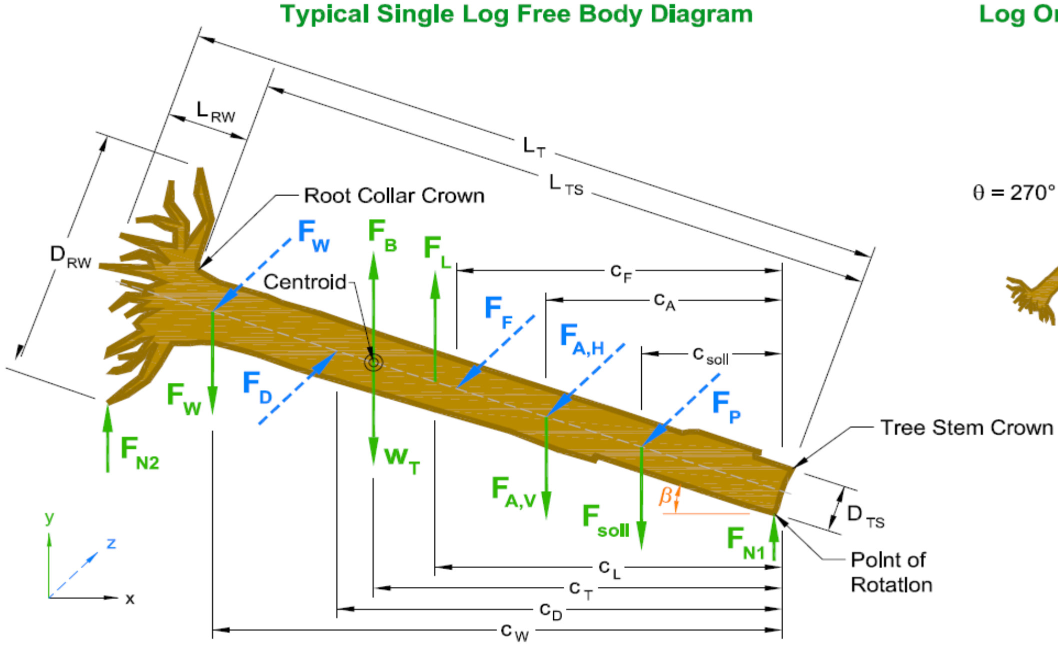


Wood Species	Rootwad	L_T (ft)	D_{TS} (ft)	L_{RW} (ft)	D_{RW} (ft)	γ_{Td} (lb/ft^3)	γ_{Tgr} (lb/ft^3)
Douglas-fir, Coast	No	20.0	1.00	-	-	33.5	38.0

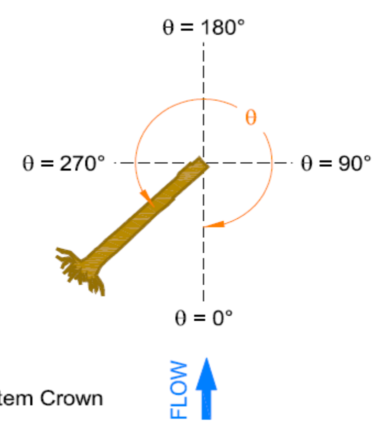
Structure Geometry	θ (deg)	β (deg)	Define Fixed Point	x_T (ft)	y_T (ft)	$y_{T,min}$ (ft)	$y_{T,max}$ (ft)	A_{Tp} (ft^2)
	70.0	22.0	Root collar: Bottom	0.00	-0.50	-0.50	7.92	4.26

Soils	Material	γ_s (lb/ft^3)	γ'_s (lb/ft^3)	ϕ (deg)	Soil Class	$L_{T,em}$ (ft)	$d_{b,max}$ (ft)	$d_{b,avg}$ (ft)
Stream Bed	Very coarse gravel	128.3	79.9	40.0	5	0.00	0.00	0.00
Bank	Gravel/cobble	137.0	85.3	41.0	4	0.00	0.00	0.00

Typical Single Log Free Body Diagram



Log Orientation (Plan View)



Wildcat Rootwad Stacked Log ID D Log #3

Vertical Force Analysis

Net Buoyancy Force

Wood	V_{TS} (ft^3)	V_{RW} (ft^3)	V_T (ft^3)	W_T (lbf)	F_B (lbf)
↑WSE	11.8	0.0	11.8	396	0
↓WS↑Thw	3.6	0.0	3.6	122	227
↓Thalweg	0.2	0.0	0.2	9	15
Total	15.7	0.0	15.7	528	243

Lift Force

C_{LT}	0.00
F_L (lbf)	0

Vertical Force Balance

F_B (lbf)	243	↑
F_L (lbf)	0	
W_T (lbf)	528	↓
F_{soil} (lbf)	0	
$F_{W,V}$ (lbf)	2,008	↓
$F_{A,V}$ (lbf)	0	
ΣF_V (lbf)	2,293	↓
FS_V	10.44	✓

Soil Ballast Force

Soil	V_{dry} (ft^3)	V_{sat} (ft^3)	V_{soil} (ft^3)	F_{soil} (lbf)
Bed	0.0	0.0	0.0	0
Bank	0.0	0.0	0.0	0
Total	0.0	0.0	0.0	0

Horizontal Force Analysis

Drag Force

A_{Tp} / A_W	Fr_L	C_{Di}	C_w	C_D*	F_D (lbf)
0.28	0.85	1.12	0.37	2.95	280

Horizontal Force Balance

F_D (lbf)	280	→
F_P (lbf)	0	
F_F (lbf)	1,959	←
$F_{W,H}$ (lbf)	0	
$F_{A,H}$ (lbf)	0	
ΣF_H (lbf)	1,679	←
FS_H	6.99	✓

Passive Soil Pressure / Friction Force

Soil	K_P	F_P (lbf)	L_{Tf} (ft)	µ	F_F (lbf)
Bed	4.60	0	3.65	0.84	949
Bank	4.81	0	3.75	0.87	1,010
Total	-	0	7.40	-	1,959

Moment Force Balance

Driving Moment Centroids / Resisting Moment Centroids

$c_{T,B}$ (ft)	c_L (ft)	c_D (ft)	$c_{T,W}$ (ft)	c_{soil} (ft)	$c_{F\&N}$ (ft)	c_P (ft)
10.0	0.0	17.0	10.0	0.0	7.2	0.0

*Distances are from the stem tip

Point of Rotation: Root Collar

Moment Force Balance

M_d (lbf)	3,045	
M_r (lbf)	73,931	
FS_M	24.28	✓

Anchor Forces

Additional Soil Ballast

V_{Adry} (ft^3)	V_{Awet} (ft^3)	c_{Asoil} (ft)	$F_{A,Vsoil}$ (lbf)	$F_{A,HP}$ (lbf)
			0	0

Mechanical Anchors

Type	c_{Am} (ft)	Soils	F_{Am} (lbf)
			0
			0

Boulder Ballast

Position	D_r (ft)	c_{Ar} (ft)	$V_{r,dry}$ (ft^3)	$V_{r,wet}$ (ft^3)	W_r (lbf)	$F_{L,r}$ (lbf)	$F_{D,r}$ (lbf)	$F_{A,Vr}$ (lbf)	$F_{A,Hr}$ (lbf)
								0	0
								0	0
								0	0

Interaction Forces with Adjacent Logs

Applied Forces from other Logs

Log ID	Position	Link	c_{WI} (ft)	$F_{W,V}$ (lbf)	$F_{W,H}$ (lbf)	$F_{W,V}$ (lbf)	$F_{W,H}$ (lbf)
D Log #2	Above	Gravity	10.0	-2,008	0	2,008	0
						0	0
						0	0
						0	0

SR 8 MP 3.16 Unnamed Tributary to Wildcat Creek

Spreadsheet developed by
Michael Rafferty, P.E.

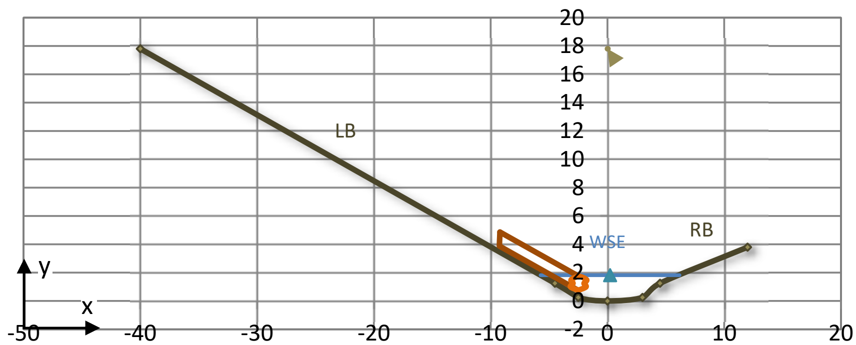
Single Log Stability Analysis Model Inputs

Site ID	Structure Type	Structure Position	Meander	Station	d_w (ft)	R_c/W_{BF}	u_{des} (ft/s)
Wildcat	Rootwad	Left bank	Straight	6+40	1.82	5.49	4.80

Multi-Log Structures	Layer	Log ID
	Stacked	D Log #4

Channel Geometry Coordinates		
Proposed	x (ft)	y (ft)
Fldpln LB	-40.00	17.80
Top LB	-4.50	1.25
Toe LB	-2.50	0.25
Thalweg	0.00	0.00
Toe RB	3.00	0.25
Top RB	4.50	1.25
Fldpln RB	12.00	3.80

Proposed Cross-Section and Structure Geometry (Looking D/S)

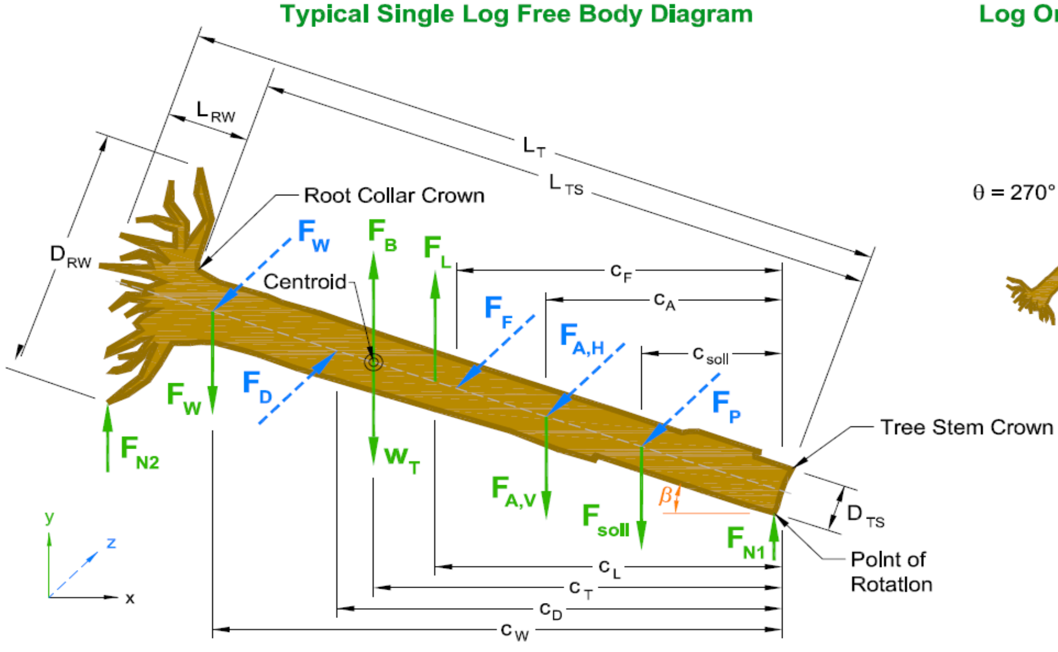


Wood Species	Rootwad	L_T (ft)	D_{TS} (ft)	L_{RW} (ft)	D_{RW} (ft)	γ_{Td} (lb/ft^3)	γ_{Tgr} (lb/ft^3)
Douglas-fir, Coast	No	20.0	1.00	-	-	33.5	38.0

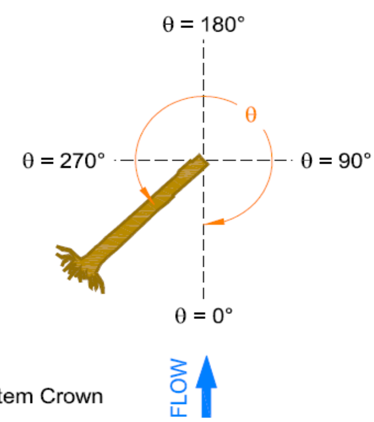
Structure Geometry	θ (deg)	β (deg)	Define Fixed Point	x_T (ft)	y_T (ft)	$y_{T,min}$ (ft)	$y_{T,max}$ (ft)	A_{Tp} (ft^2)
	160.0	9.0	Root collar: Bottom	-2.50	0.75	0.75	4.87	1.26

Soils	Material	γ_s (lb/ft^3)	γ'_s (lb/ft^3)	ϕ (deg)	Soil Class	$L_{T,em}$ (ft)	$d_{b,max}$ (ft)	$d_{b,avg}$ (ft)
Stream Bed	Very coarse gravel	128.3	79.9	40.0	5	0.00	0.00	0.00
Bank	Gravel/cobble	137.0	85.3	41.0	4	0.00	0.00	0.00

Typical Single Log Free Body Diagram



Log Orientation (Plan View)



Vertical Force Analysis

Net Buoyancy Force

Wood	V_{TS} (ft^3)	V_{RW} (ft^3)	V_T (ft^3)	W_T (lbf)	F_B (lbf)
↑WSE	12.8	0.0	12.8	430	0
↓WS↑Thw	2.9	0.0	2.9	97	181
↓Thalweg	0.0	0.0	0.0	0	0
Total	15.7	0.0	15.7	527	181

Lift Force

C_{LT}	0.00
F_L (lbf)	0

Vertical Force Balance

F_B (lbf)	181
F_L (lbf)	0
W_T (lbf)	527
F_{soil} (lbf)	0
$F_{W,V}$ (lbf)	1,990
$F_{A,V}$ (lbf)	0
ΣF_V (lbf)	2,336
FS_V	13.94

Soil Ballast Force

Soil	V_{dry} (ft^3)	V_{sat} (ft^3)	V_{soil} (ft^3)	F_{soil} (lbf)
Bed	0.0	0.0	0.0	0
Bank	0.0	0.0	0.0	0
Total	0.0	0.0	0.0	0

Horizontal Force Analysis

Drag Force

A_{Tp} / A_W	Fr_L	C_{Di}	C_w	C_D*	F_D (lbf)
0.08	0.85	0.56	0.43	1.18	33

Horizontal Force Balance

F_D (lbf)	33
F_P (lbf)	0
F_F (lbf)	1,961
$F_{W,H}$ (lbf)	0
$F_{A,H}$ (lbf)	0
ΣF_H (lbf)	1,927
FS_H	59.03

Passive Soil Pressure / Friction Force

Soil	K_P	F_P (lbf)	L_{Tf} (ft)	μ	F_F (lbf)
Bed	4.60	0	2.00	0.84	1,961
Bank	4.81	0	0.00	0.87	0
Total	-	0	2.00	-	1,961

Moment Force Balance

Driving Moment Centroids / Resisting Moment Centroids

$c_{T,B}$ (ft)	c_L (ft)	c_D (ft)	$c_{T,W}$ (ft)	c_{soil} (ft)	$c_{F\&N}$ (ft)	c_P (ft)
10.0	0.0	16.6	10.0	0.0	0.0	0.0

*Distances are from the stem tip

Point of Rotation: Root Collar

Moment Force Balance

M_d (lbf)	1,894
M_r (lbf)	99,913
FS_M	52.74

Anchor Forces

Additional Soil Ballast

V_{Adry} (ft^3)	V_{Awet} (ft^3)	c_{Asoil} (ft)	$F_{A,Vsoil}$ (lbf)	$F_{A,HP}$ (lbf)
			0	0

Mechanical Anchors

Type	c_{Am} (ft)	Soils	F_{Am} (lbf)
			0
			0

Boulder Ballast

Position	D_r (ft)	c_{Ar} (ft)	$V_{r,dry}$ (ft^3)	$V_{r,wet}$ (ft^3)	W_r (lbf)	$F_{L,r}$ (lbf)	$F_{D,r}$ (lbf)	$F_{A,Vr}$ (lbf)	$F_{A,Hr}$ (lbf)
								0	0
								0	0
								0	0

Interaction Forces with Adjacent Logs

Applied Forces from other Logs

Log ID	Position	Link	c_{WI} (ft)	$F_{W,V}$ (lbf)	$F_{W,H}$ (lbf)	$F_{W,V}$ (lbf)		$F_{W,H}$ (lbf)
D Log #1	Above	Gravity	15.0	-1,990	0	1,990	↓	0
						0		0
						0		0
						0		0

SR 8 MP 3.16 Unnamed Tributary to Wildcat Creek
Notation, Units, and List of Symbols

Notation

Symbol	Description	Unit
A_W	Wetted area of channel at design discharge	ft^2
A_{Tp}	Projected area of wood in plane perpendicular to flow	ft^2
c_D	Centroid of the drag force along log axis	ft
c_{Am}	Centroid of a mechanical anchor along log axis	ft
c_{Ar}	Centroid of a ballast boulder along log axis	ft
c_{Asoil}	Centroid of the added ballast soil along log axis	ft
$c_{F\&N}$	Centroid of friction and normal forces along log axis	ft
c_L	Centroid of the lift force along log axis	ft
c_P	Centroid of the passive soil force along log axis	ft
c_{soil}	Centroid of the vertical soil forces along log axis	ft
$c_{T,B}$	Centroid of the buoyancy force along log axis	ft
$c_{T,W}$	Centroid of the log volume along log axis	ft
c_{WI}	Centroid of a wood interaction force along log axis	ft
C_{Lrock}	Coefficient of lift for submerged boulder	-
C_{LT}	Effective coefficient of lift for submerged tree	-
C_{Di}	Base coefficient of drag for tree, before adjustments	-
C_D*	Effective coefficient of drag for submerged tree	-
C_{Di}	Base coefficient of drag for tree, before adjustments	-
C_W	Wave drag coefficient of submerged tree	-
$d_{b,avg}$	Average buried depth of log	ft
$d_{b,max}$	Maximum buried depth of log	ft
d_w	Maximum flow depth at design discharge in reach	ft
D_{50}	Median grain size in millimeters (SI units)	mm
D_r	Equivalent diameter of boulder	ft
D_{RW}	Assumed diameter of rootwad	ft
D_{TS}	Nominal diameter of tree stem (DBH)	ft
DF_{RW}	Diameter factor for rootwad ($DF_{RW} = D_{RW}/D_{TS}$)	-
e	Void ratio of soils	-
$F_{A,H}$	Total horizontal load capacity of anchor techniques	lbf
$F_{A,HP}$	Passive soil pressure applied to log from soil ballast	lbf
$F_{A,Hr}$	Horizontal resisting force on log from boulder	lbf
F_{Am}	Load capacity of mechanical anchor	lbf
$F_{A,V}$	Total vertical load capacity of anchor techniques	lbf
$F_{A,Vr}$	Vertical resisting force on log from boulder	lbf
$F_{A,Vsoil}$	Vertical soil loading on log from added ballast soil	lbf
F_B	Buoyant force applied to log	lbf
F_D	Drag forces applied to log	lbf
$F_{D,r}$	Drag forces applied to boulder	lbf
F_F	Friction force applied to log	lbf
F_H	Resultant horizontal force applied to log	lbf
F_L	Lift force applied to log	lbf
$F_{L,r}$	Lift force applied to boulder	lbf
F_P	Passive soil pressure force applied to log	lbf
F_{soil}	Vertical soil loading on log	lbf
$F_{W,H}$	Horizontal forces from interactions with other logs	lbf
$F_{W,V}$	Vertical forces from interactions with other logs	lbf

Notation (continued)

Symbol	Description	Unit
F_V	Resultant vertical force applied to log	lbf
Fr_L	Log Froude number	-
FS_V	Factor of Safety for Vertical Force Balance	-
FS_H	Factor of Safety for Horizontal Force Balance	-
FS_M	Factor of Safety for Moment Force Balance	-
g	Gravitational acceleration constant	ft/s^2
K_P	Coefficient of Passive Earth Pressure	-
$L_{T,em}$	Total embedded length of log	ft
L_{RW}	Assumed length of rootwad	ft
L_T	Total length of tree (including rootwad)	ft
L_{Tf}	Length of log in contact with bed or banks	ft
L_{TS}	Length of tree stem (not including rootwad)	ft
$L_{TS,ex}$	Exposed length of tree stem	ft
LF_{RW}	Length factor for rootwad ($LF_{RW} = L_{RW}/D_{TS}$)	-
M_d	Driving moment about embedded tip	lbf
M_r	Driving moment about embedded tip	lbf
N	Blow count of standard penetration test	-
p_o	Porosity of soil volume	-
Q_{des}	Design discharge	cfs
R	Radius	ft
R_c	Radius of curvature at channel centerline	ft
SG_r	Specific gravity of quartz particles	-
SG_T	Specific gravity of tree	-
u_{avg}	Average velocity of cross section in reach	ft/s
u_{des}	Design velocity	ft/s
u_m	Adjusted velocity at outer meander bend	ft/s
V_{dry}	Volume of soils above stage level of design flow	ft^3
V_{sat}	Volume of soils below stage level of design flow	ft^3
V_{soil}	Total volume of soils over log	ft^3
V_{RW}	Volume of rootwad	ft^3
V_S	Volume of solids in soil (void ratio calculation)	ft^3
V_T	Total volume of log	ft^3
V_{TS}	Total volume of tree	ft^3
V_V	Volume of voids in soil	ft^3
V_{Adry}	Volume of ballast above stage of design flow	ft^3
V_{Awet}	Volume of ballast below stage of design flow	ft^3
$V_{r,dry}$	Volume of boulder above stage of design flow	ft^3
$V_{r,wet}$	Volume of boulder below stage of design flow	ft^3
W_{BF}	Bankfull width at structure site	ft
W_r	Effective weight of boulder	lbf
W_T	Total log weight	lbf
x	Horizontal coordinate (distance)	ft
y	Vertical coordinate (elevation)	ft
$y_{T,max}$	Minimum elevation of log	ft
$y_{T,min}$	Maximum elevation of log	ft

Greek Symbols

Symbol	Description	Unit
β	Tilt angle from stem tip to vertical	deg
γ_{bank}	Dry specific weight of bank soils	lb/ft^3
$\gamma_{bank,sat}$	Saturated unit weight of bank soils	lb/ft^3
γ'_{bank}	Effective buoyant unit weight of bank soils	lb/ft^3
γ_{bed}	Dry specific weight of stream bed substrate	lb/ft^3
γ'_{bed}	Effective buoyant unit weight of stream bed substrate	lb/ft^3
γ_{rock}	Dry unit weight of boulders	lb/ft^3
γ_s	Dry specific weight of soil	lb/ft^3
γ'_s	Effective buoyant unit weight of soil	lb/ft^3
γ_{Td}	Air-dried unit weight of tree (12% MC basis)	lb/ft^3
γ_{Tgr}	Green unit weight of tree	lb/ft^3
γ_w	Specific weight of water at 50ºF	lb/ft^3
η	Rootwad porosity	-
θ	Rootwad (or large end of log) orientation to flow	deg
μ	Coefficient of friction	-
ν	Kinematic viscosity of water at 50ºF	ft/s^2
Σ	Sum of forces	-
ϕ_{bank}	Internal friction angle of bank soils	deg
ϕ_{bed}	Internal friction angle of stream bed substrate	deg

Units

Notation	Description
cfs	Cubic feet per second
ft	Feet
lb	Pound
lbf	Pounds force
kg	Kilograms
m	Meters
mm	Millimeters
s	Seconds
yr	Year

Abbreviations

Notation	Description
ARI	Average return interval
Avg	Average
DBH	Diameter at breast height
deg	Degrees
Dia	Diameter
Dist	Distance
D/S	Downstream
ELJ	Engineered log jam
Ex	Example
Fldpln	Floodplain
H&H	Hydrologic and hydraulic
ID	Identification
i.e.	That is
LB	Left bank
LW	Large wood
Max	Maximum
MC	Moisture content
Min	Minimum
ML	Multi-log
SL	Single log
N/A	Not applicable
no	Number
Pt	Point
rad	Radians
RB	Right bank
RW	Rootwad
SL	Single log
Thw	Thalweg (lowest elevation in channel bed)
Typ	Typical
U.S.	United States
WS	Water surface
WSE	Water surface elevation
↑	Above
↓	Below

Appendix G: Future Projections for Climate-Adapted Culvert Design

Future Projections for Climate-Adapted Culvert Design

Project Name:	993724
Stream Name:	
Drainage Area:	43 ac

Projected mean percent change in bankfull flow:

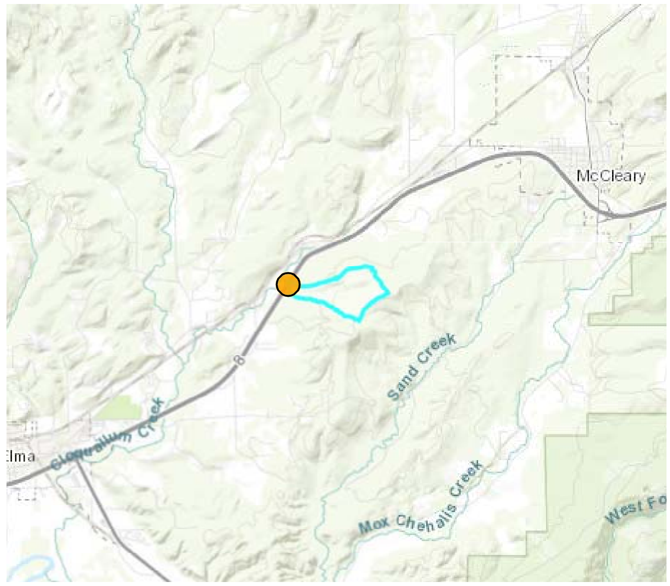
2040s:	12%
2080s:	15.9%

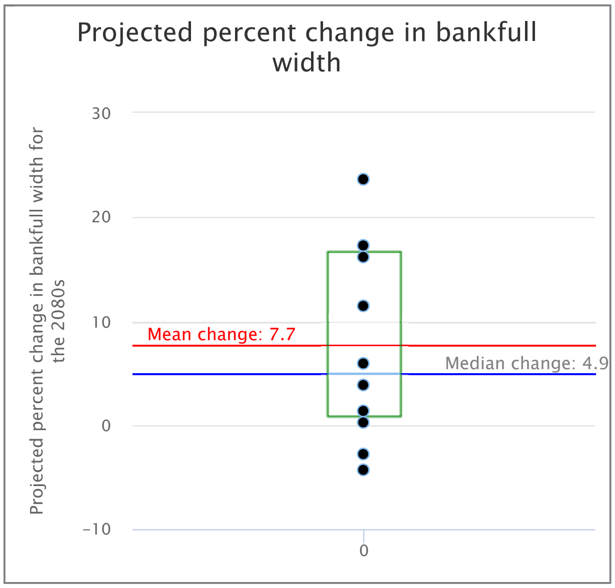
Projected mean percent change in bankfull width:

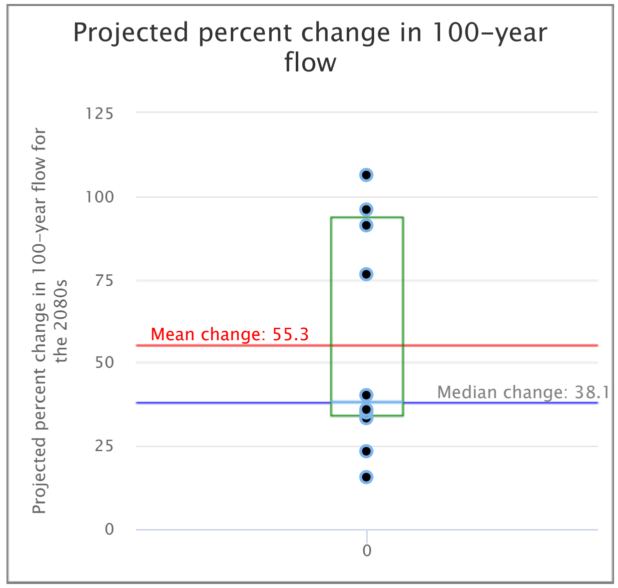
2040s:	5.8%
2080s:	7.7%

Projected mean percent change in 100-year flood:

2040s:	38.9%
2080s:	55.3%







Black dots are projections from 10 separate models

The Washington Department of Fish and Wildlife makes no guarantee concerning the data's content, accuracy, precision, or completeness. WDFW makes no warranty of fitness for a particular purpose and assumes no liability for the data represented here.

Appendix H: SRH-2D Model Results

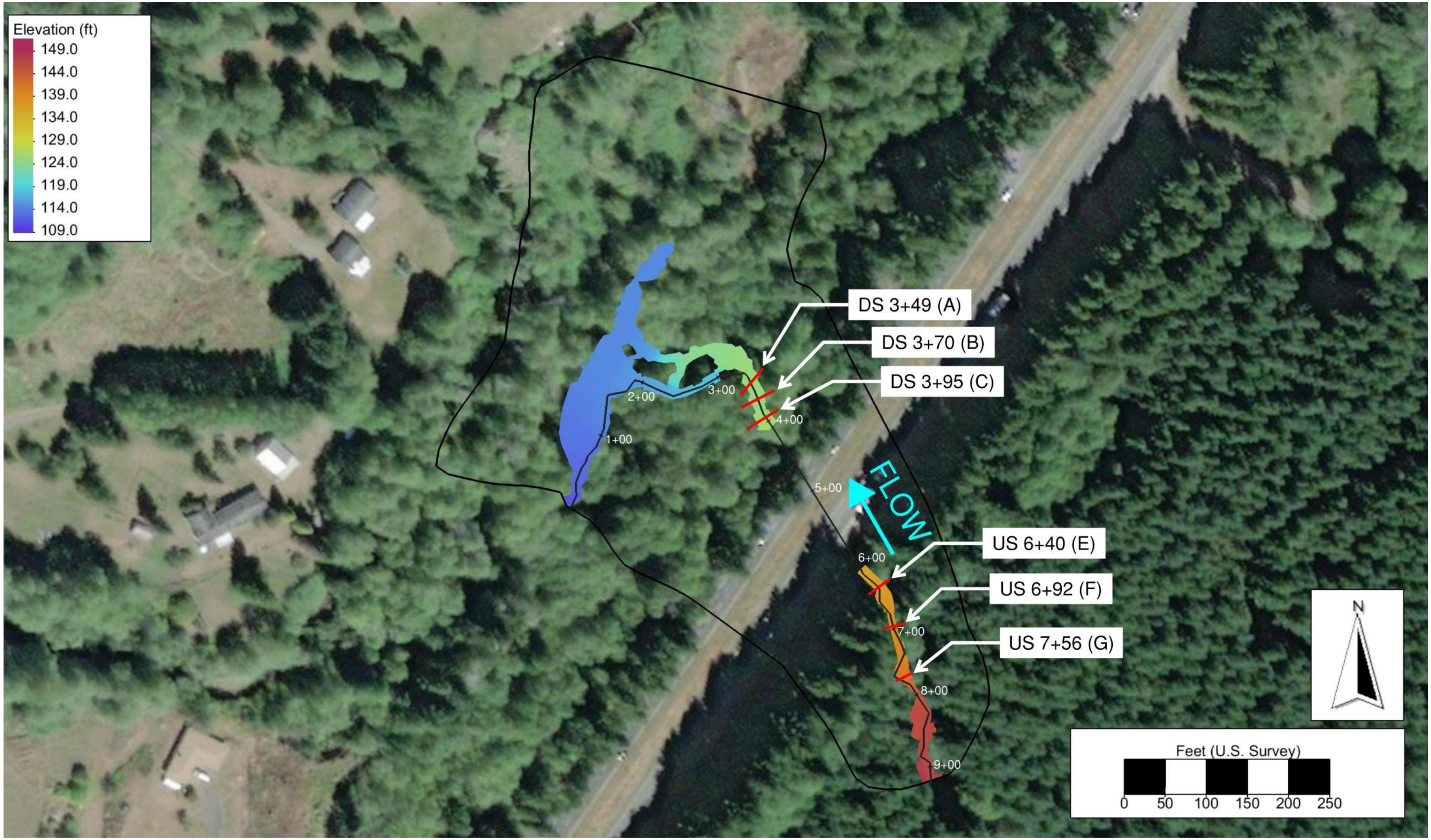


Figure H.1: Existing conditions 2-year water surface elevation

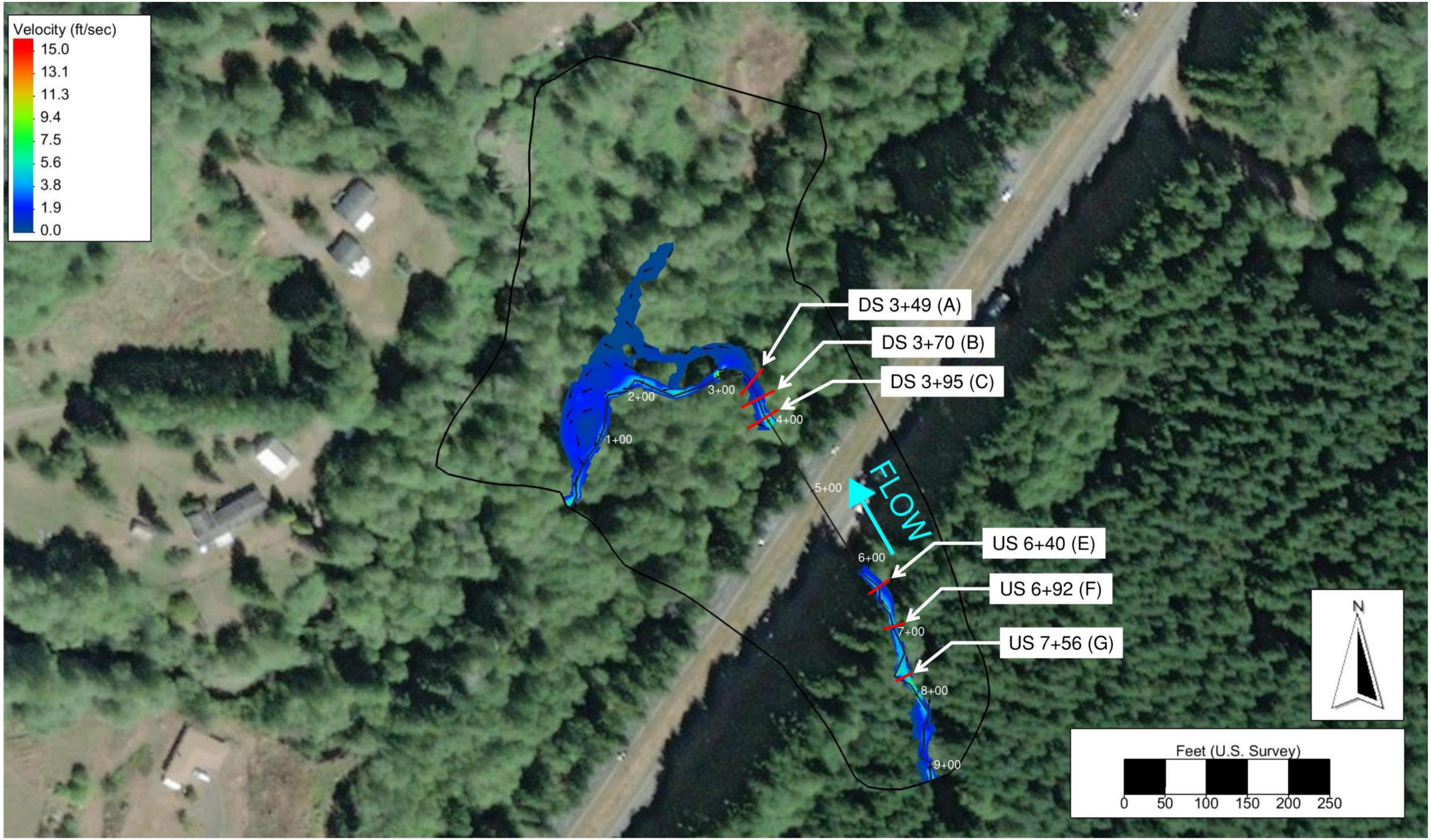


Figure H.2: Existing conditions 2-year velocity

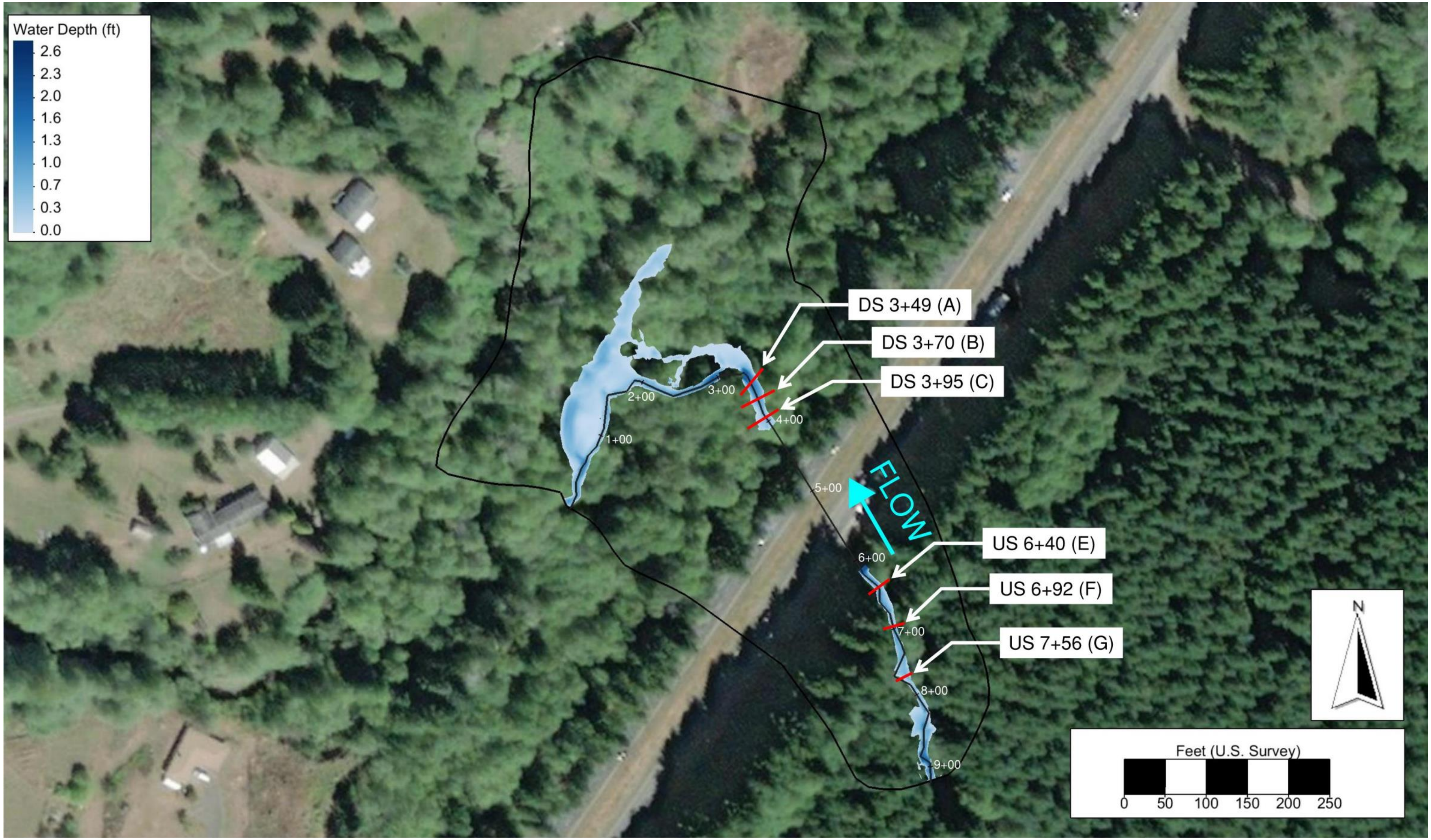


Figure H.3: Existing conditions 2-year water depth

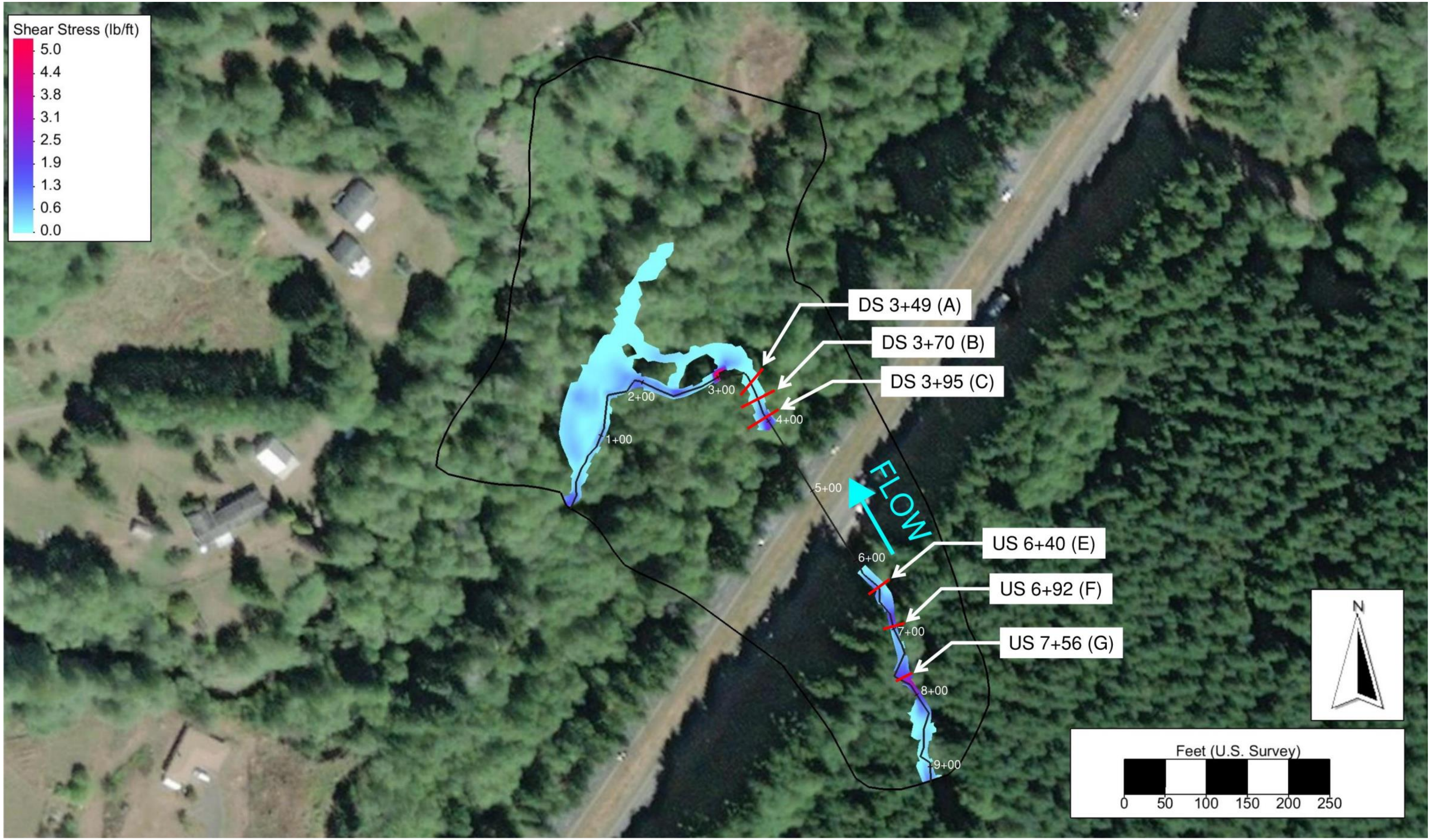


Figure H.4: Existing conditions 2-year shear stress

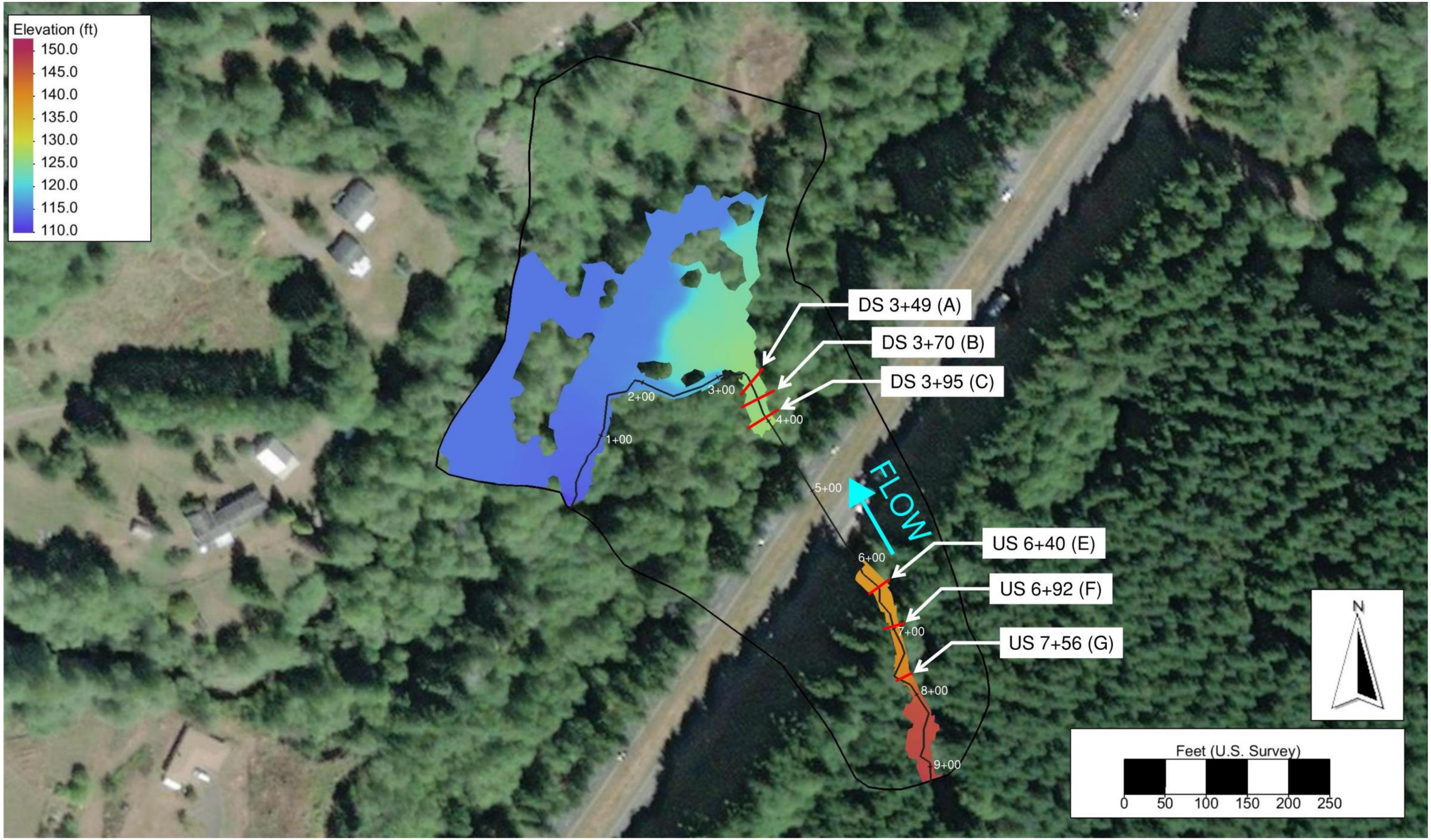


Figure H.5: Existing conditions 100-year water surface elevation

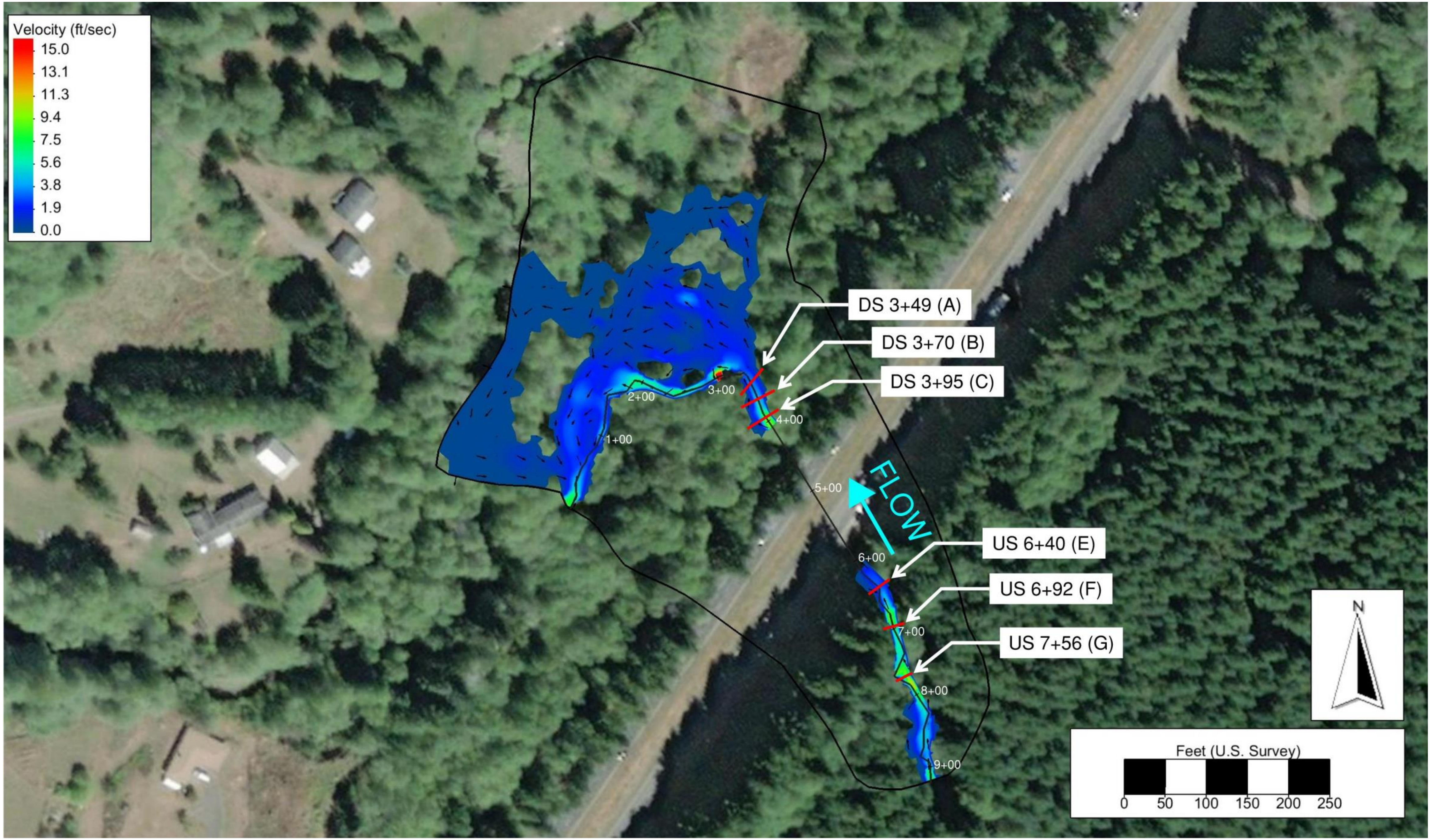


Figure H.6: Existing conditions 100-year velocity

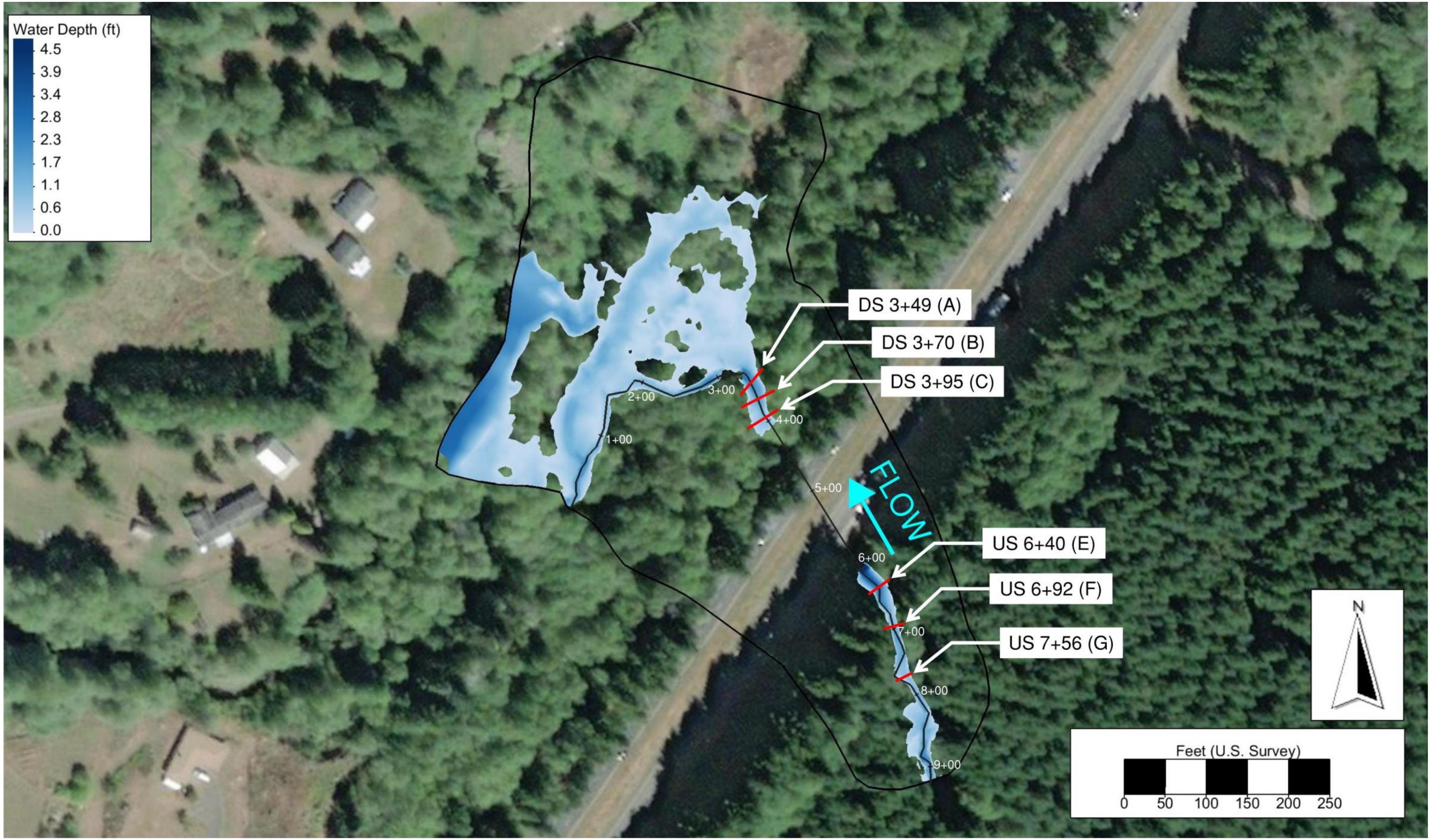


Figure H.7: Existing conditions 100-year water depth

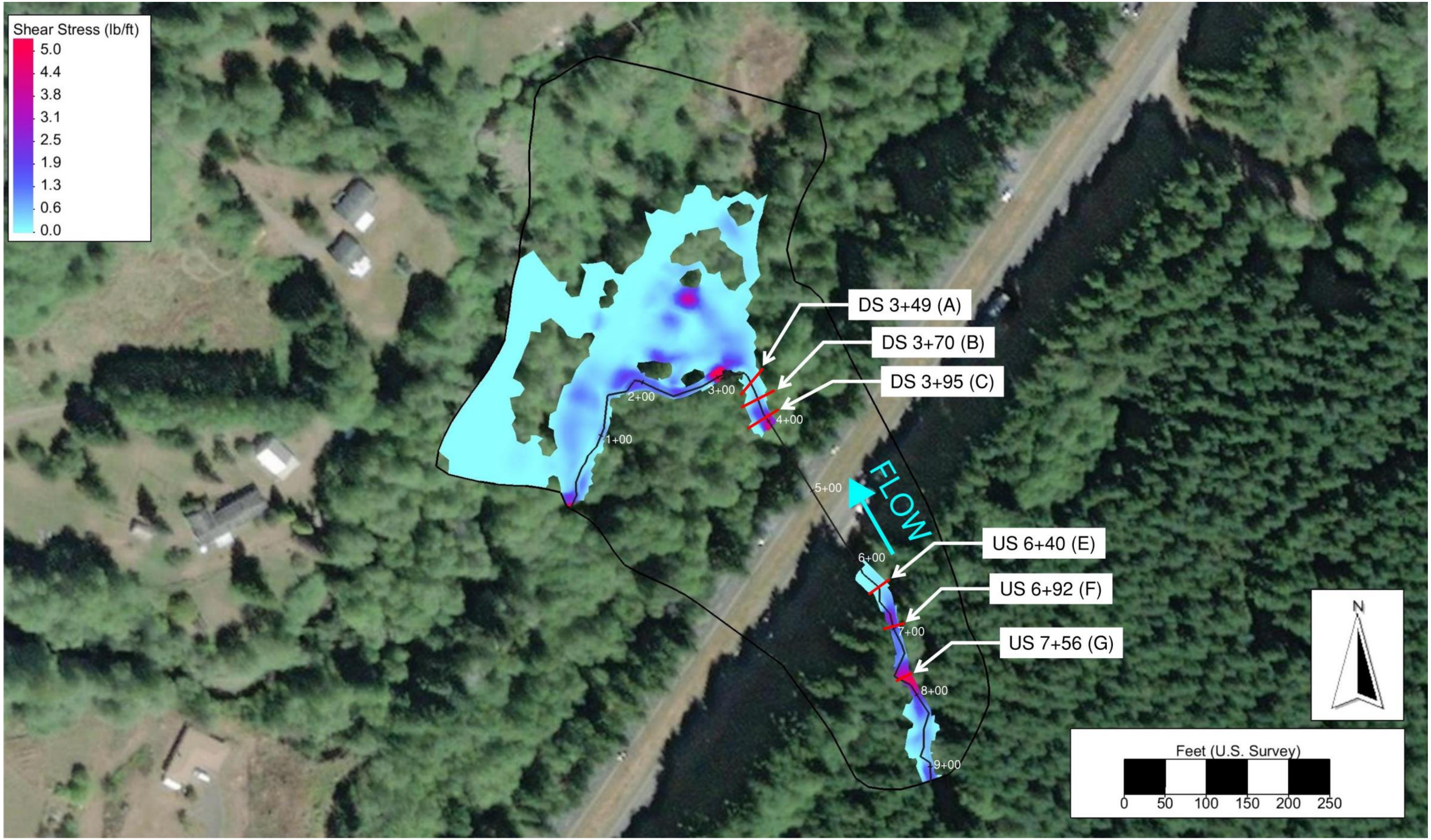


Figure H.8: Existing conditions 100-year shear stress

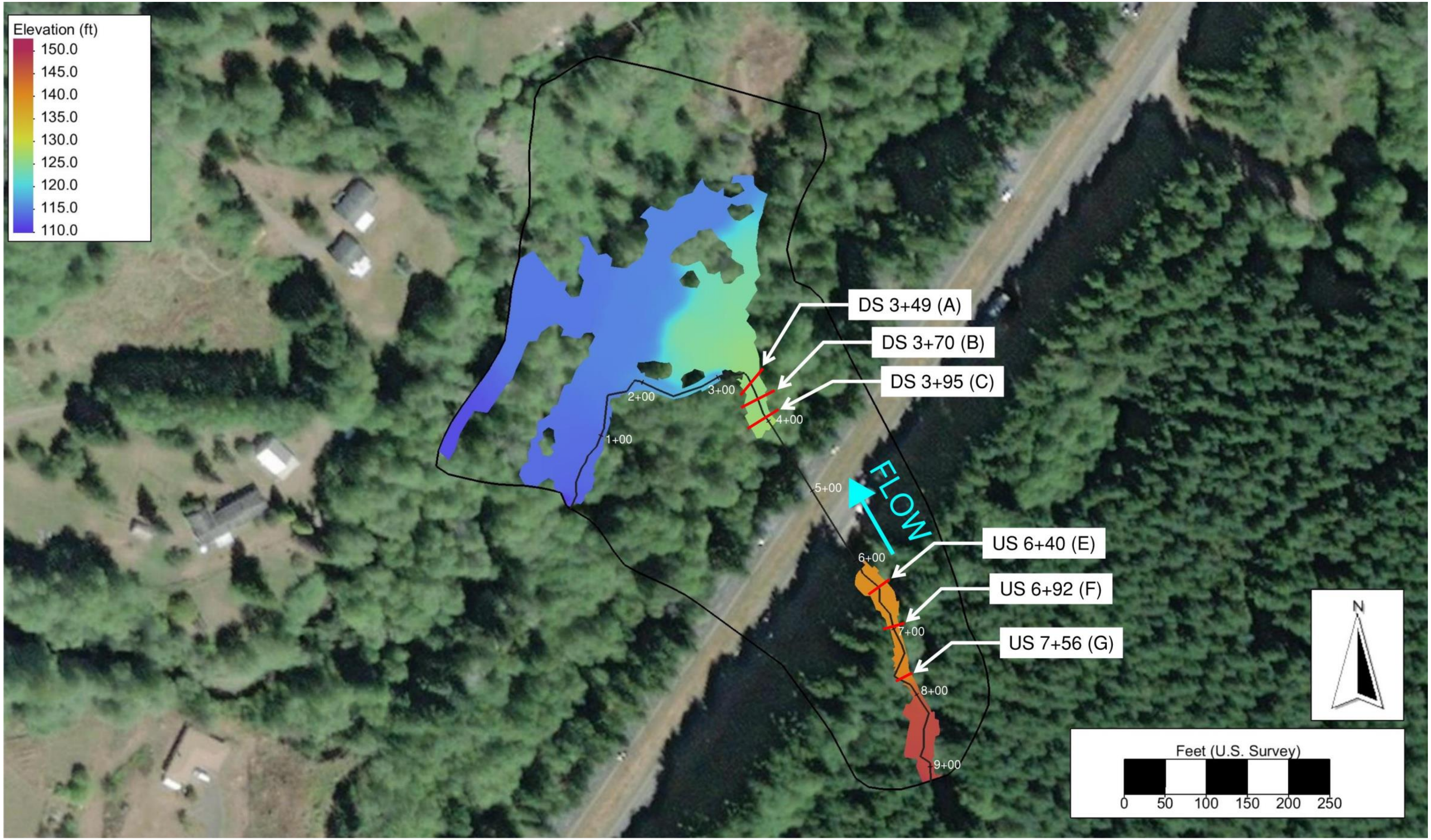


Figure H.9: Existing conditions 500-year water surface elevation

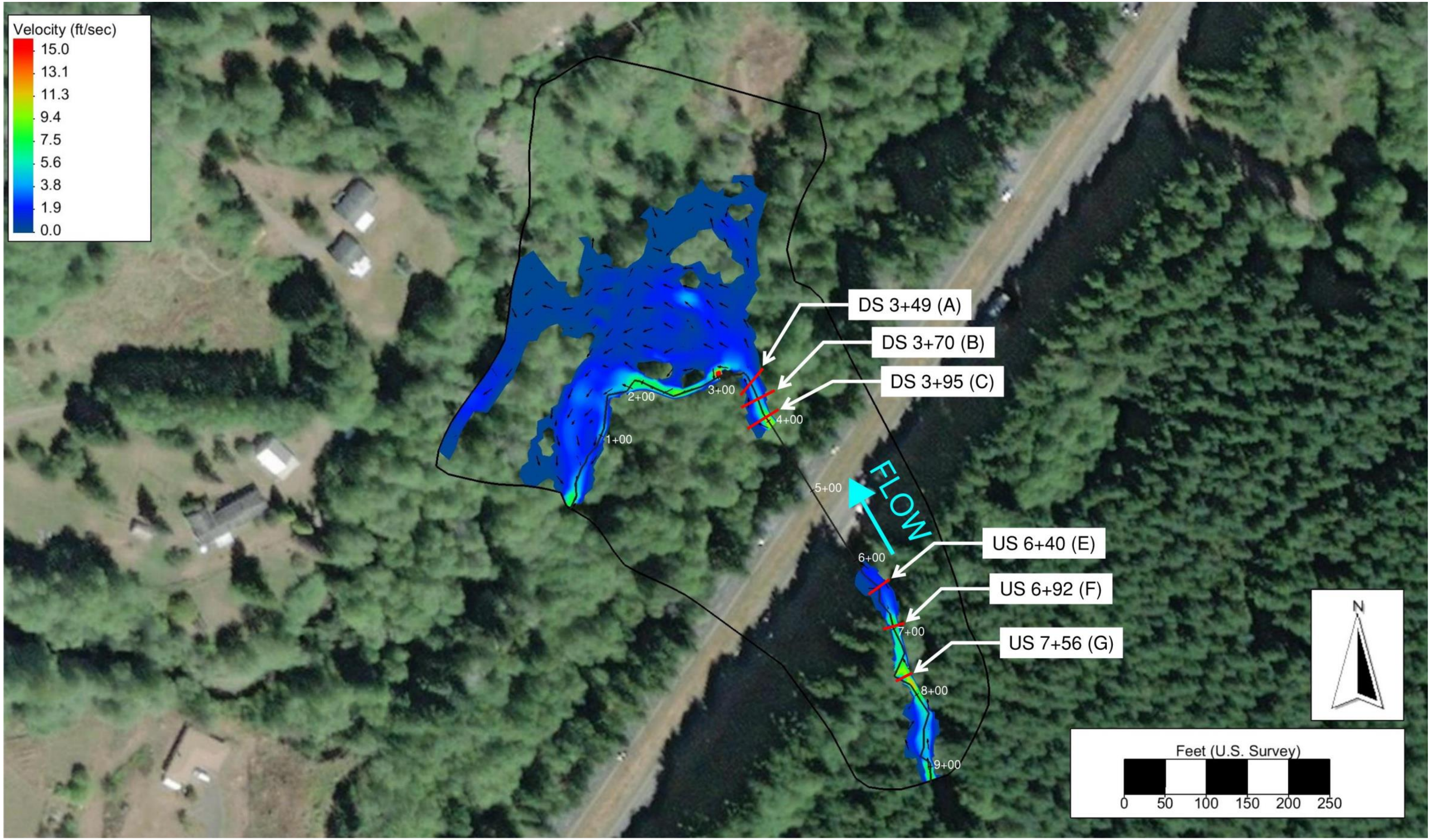


Figure H.10: Existing conditions 500-year velocity

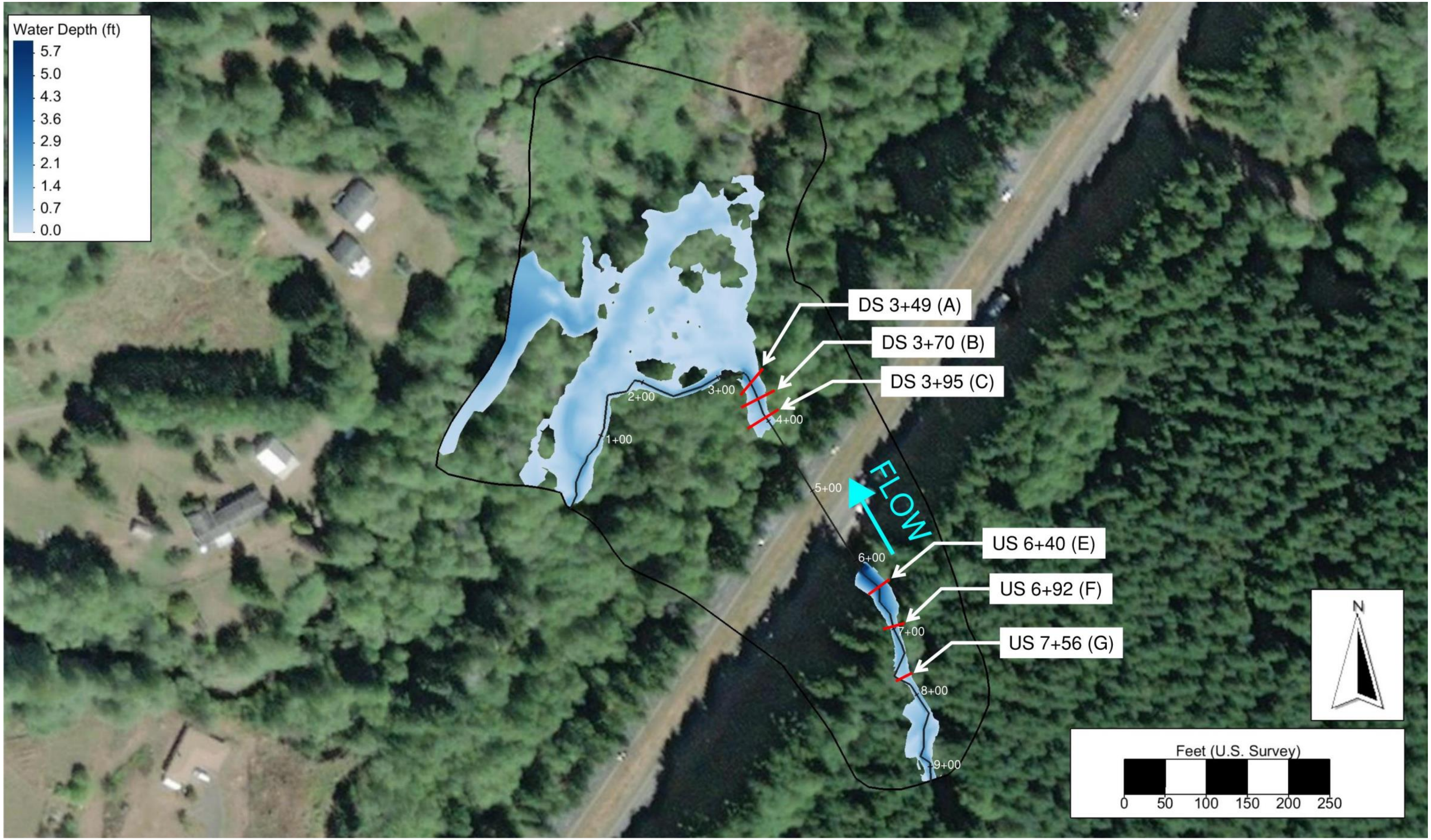


Figure H.11: Existing conditions 500-year water depth

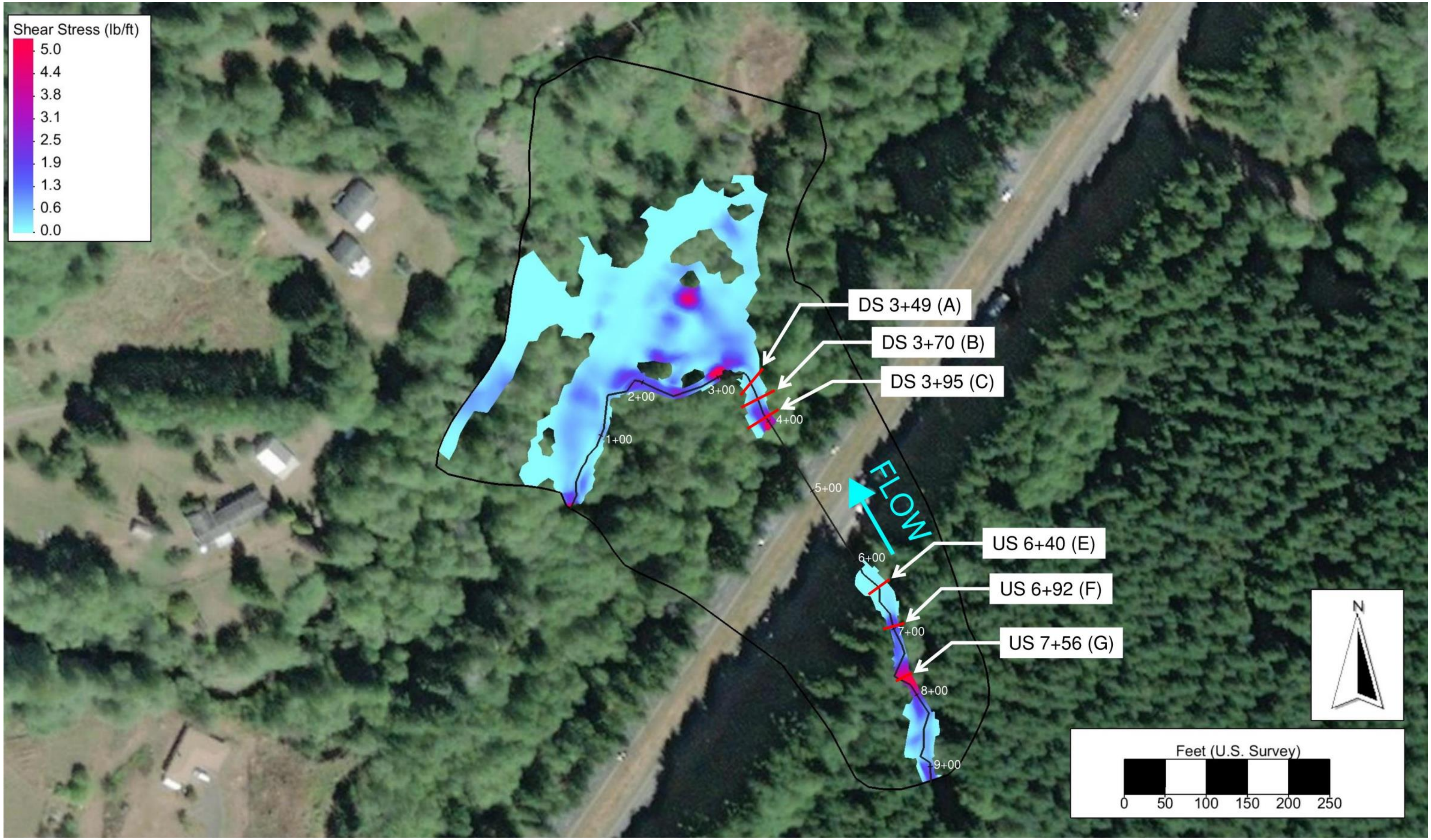


Figure H.12: Existing conditions 500-year shear stress

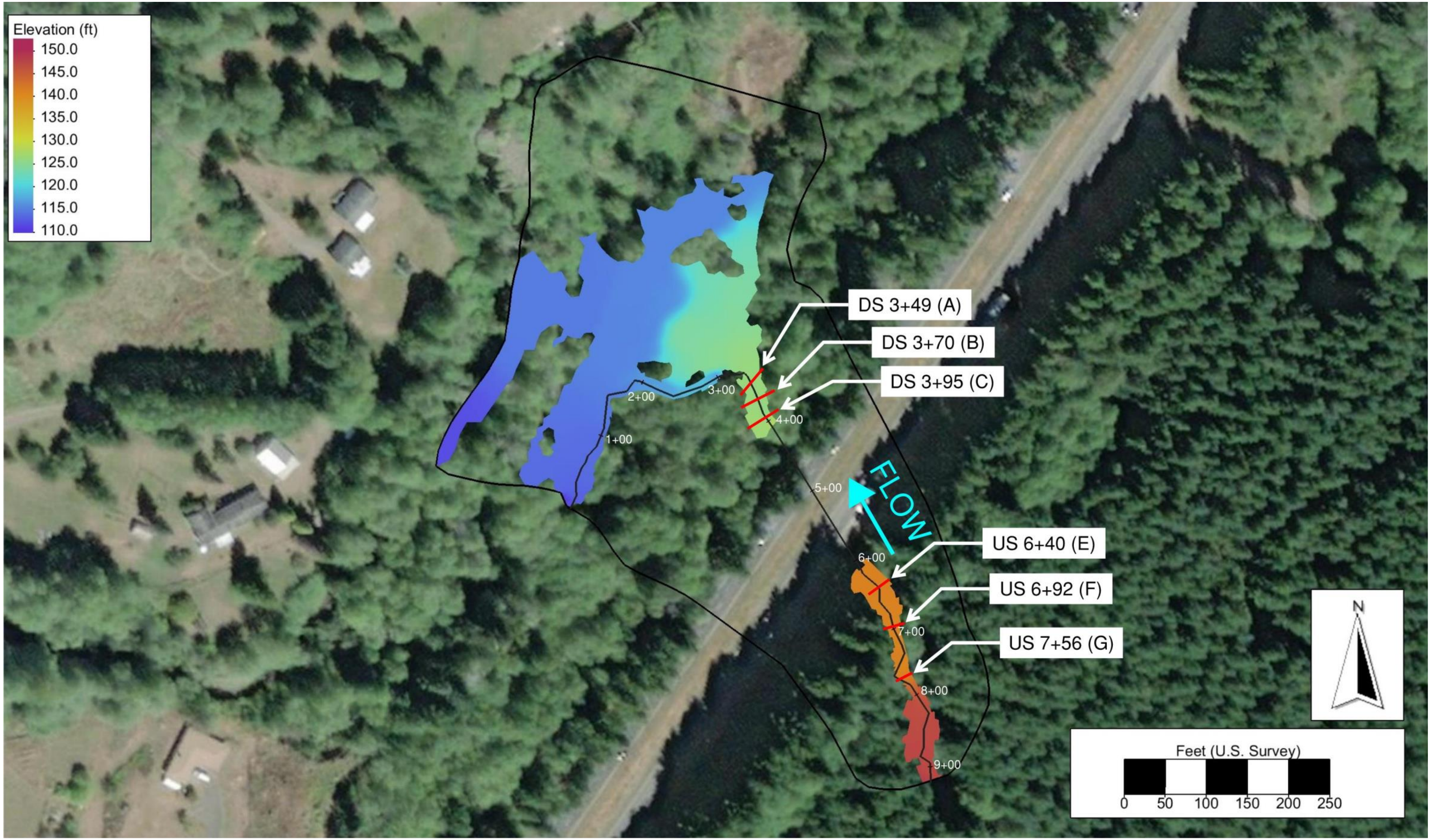


Figure H.13: Existing conditions 2080 projected 100-year water surface elevation

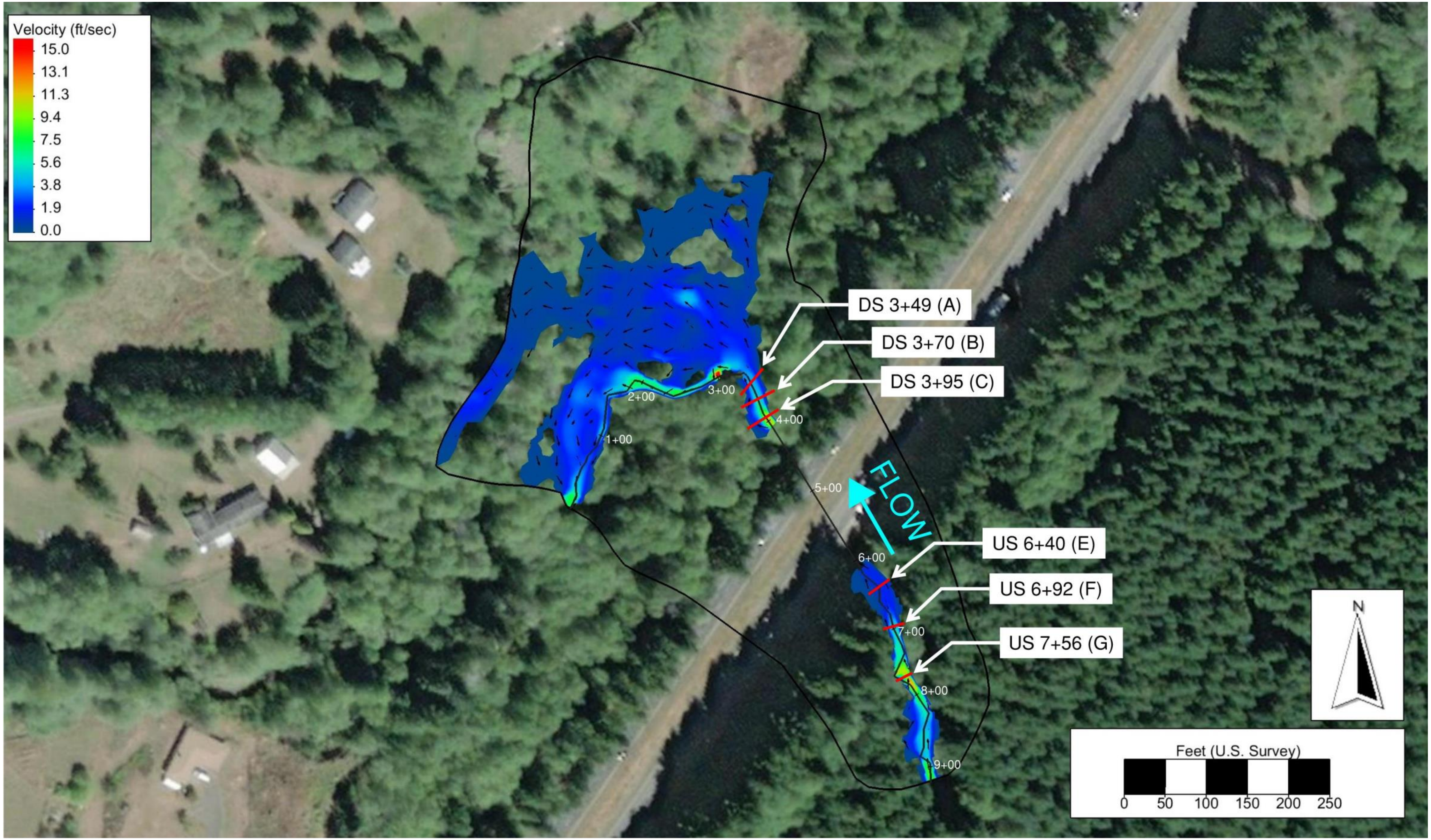


Figure H.14: Existing conditions 2080 projected 100-year velocity

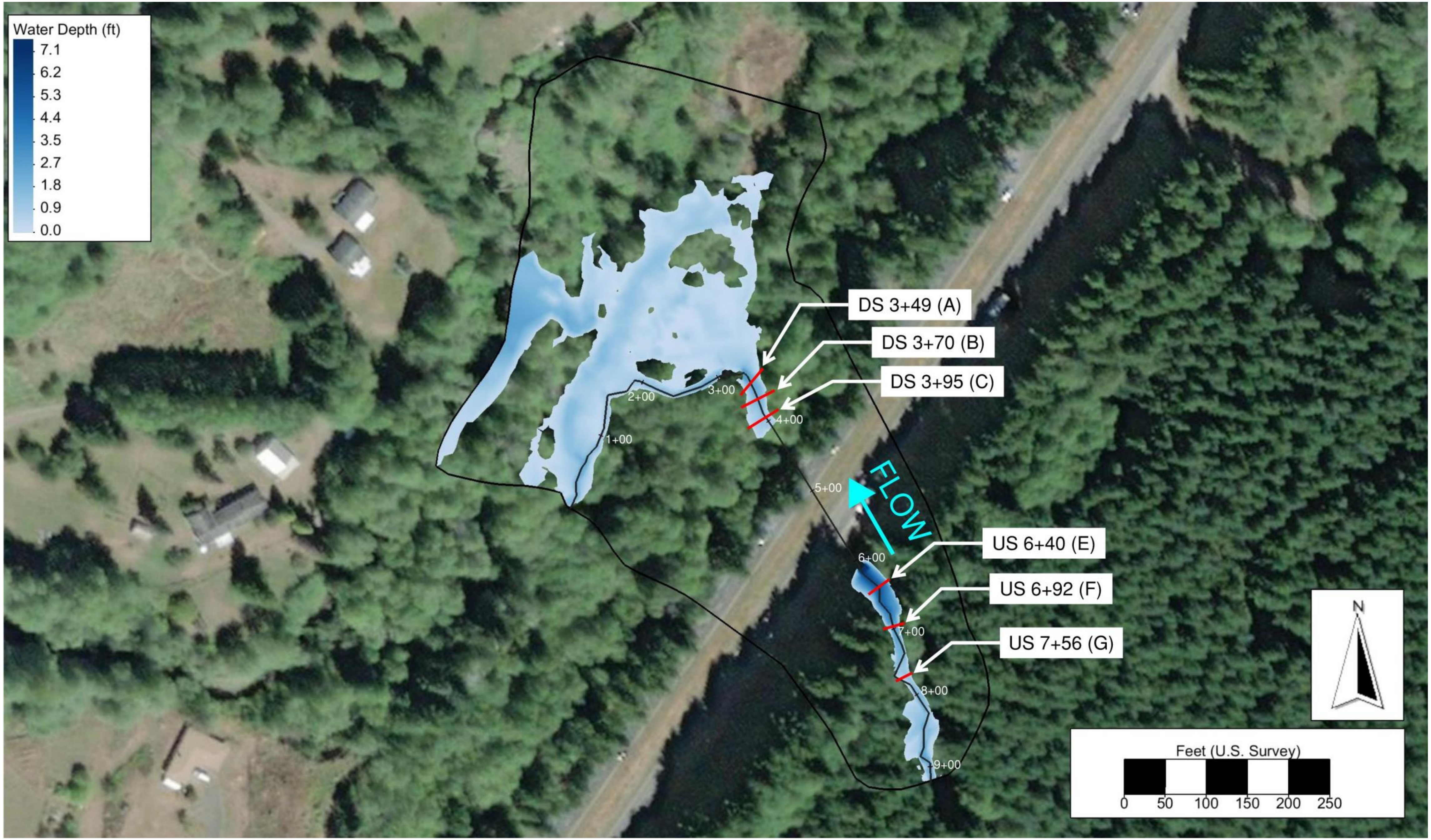


Figure H.15: Existing conditions 2080 projected 100-year water depth

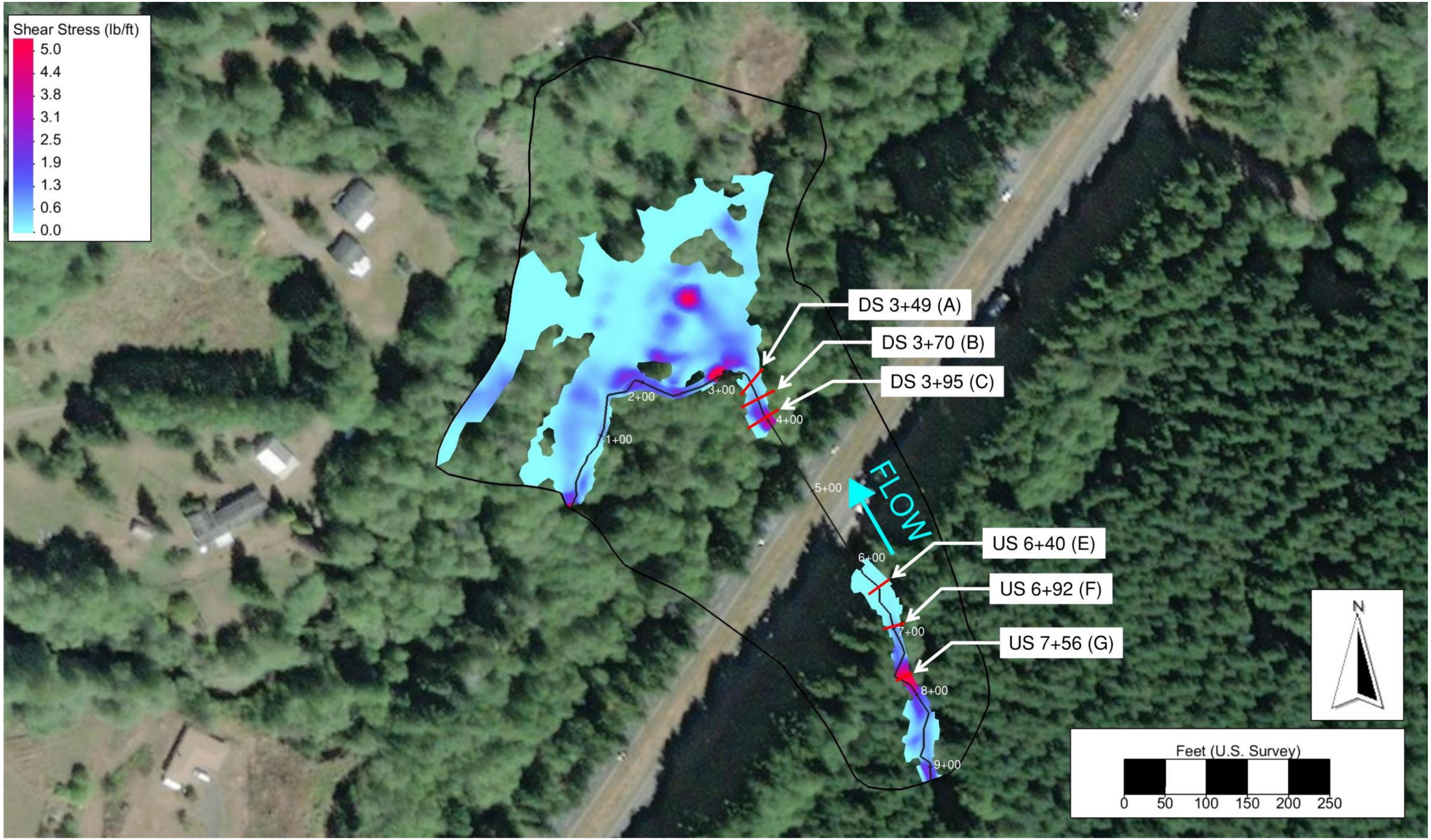


Figure H.16: Existing conditions 2080 projected 100-year shear stress

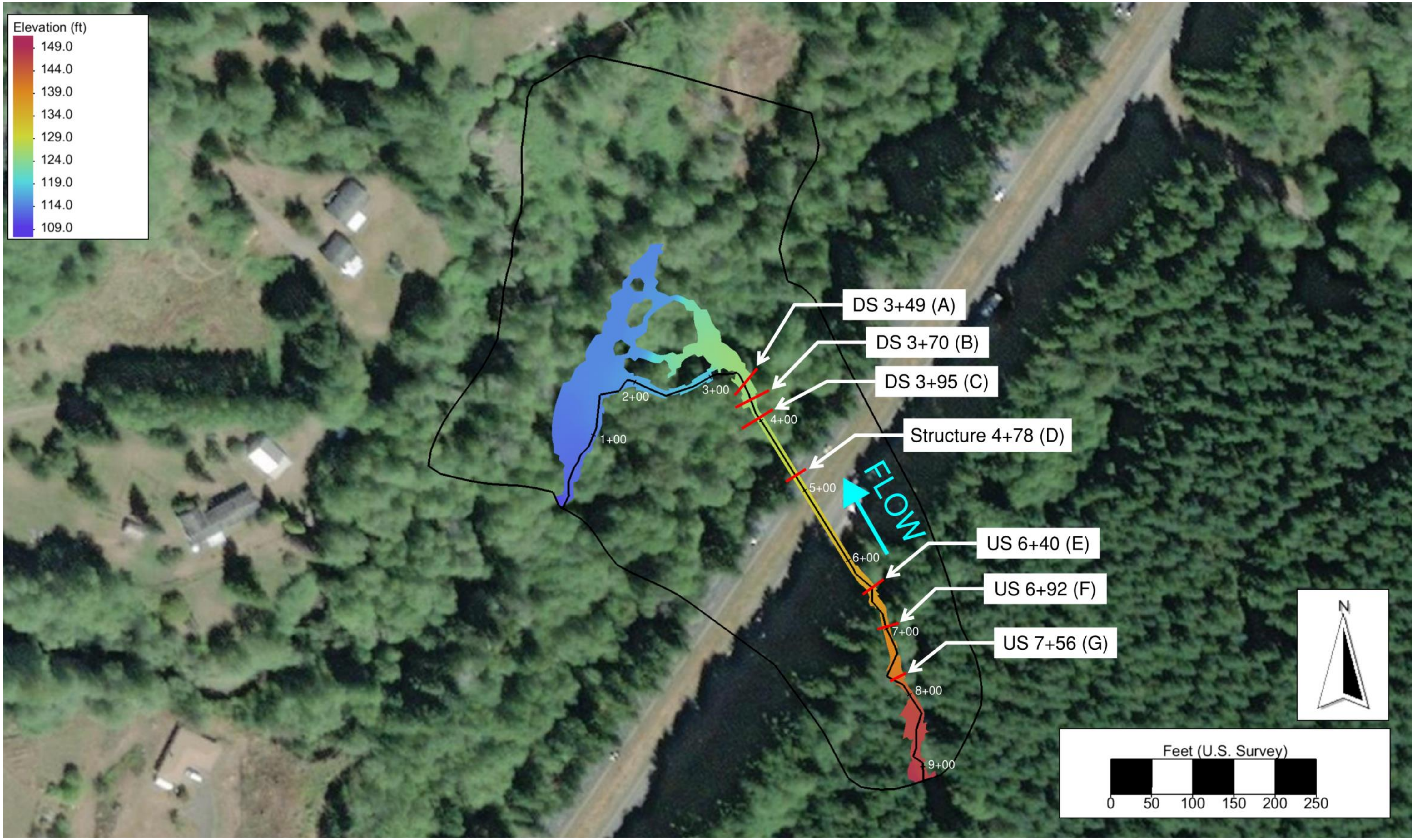


Figure H.17: Proposed conditions 2-year water surface elevation

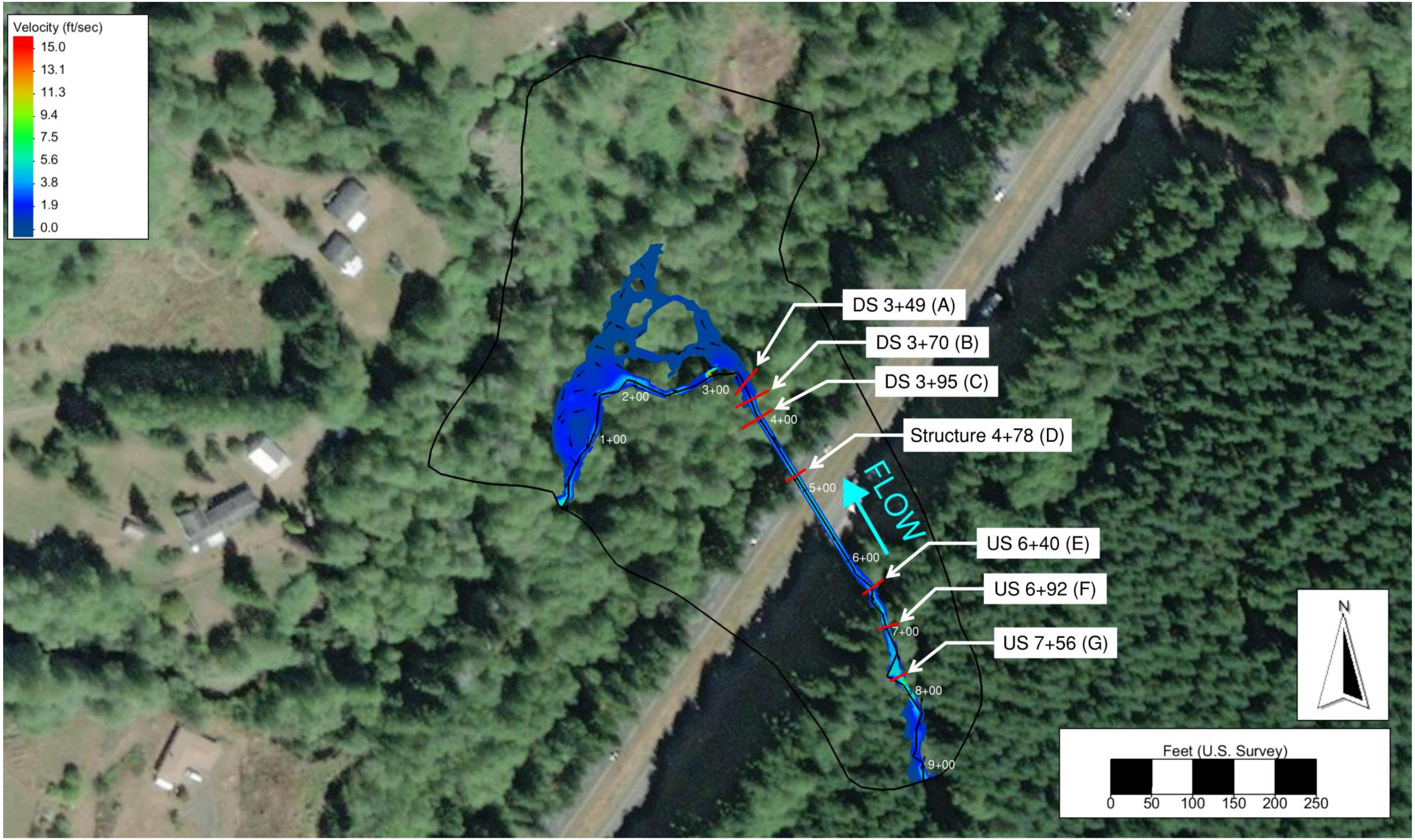


Figure H.18: Proposed conditions 2-year velocity

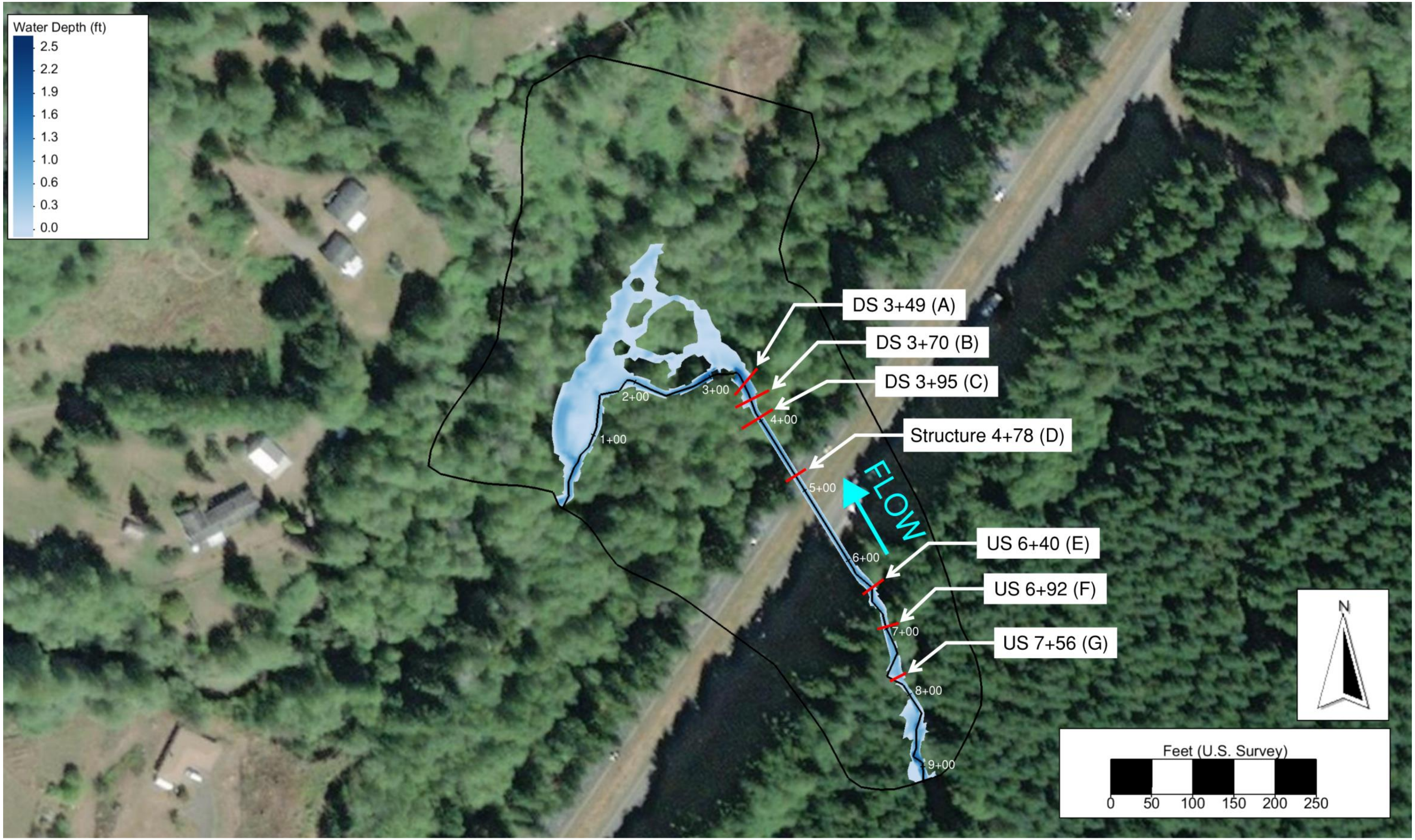


Figure H.19: Proposed conditions 2-year water depth

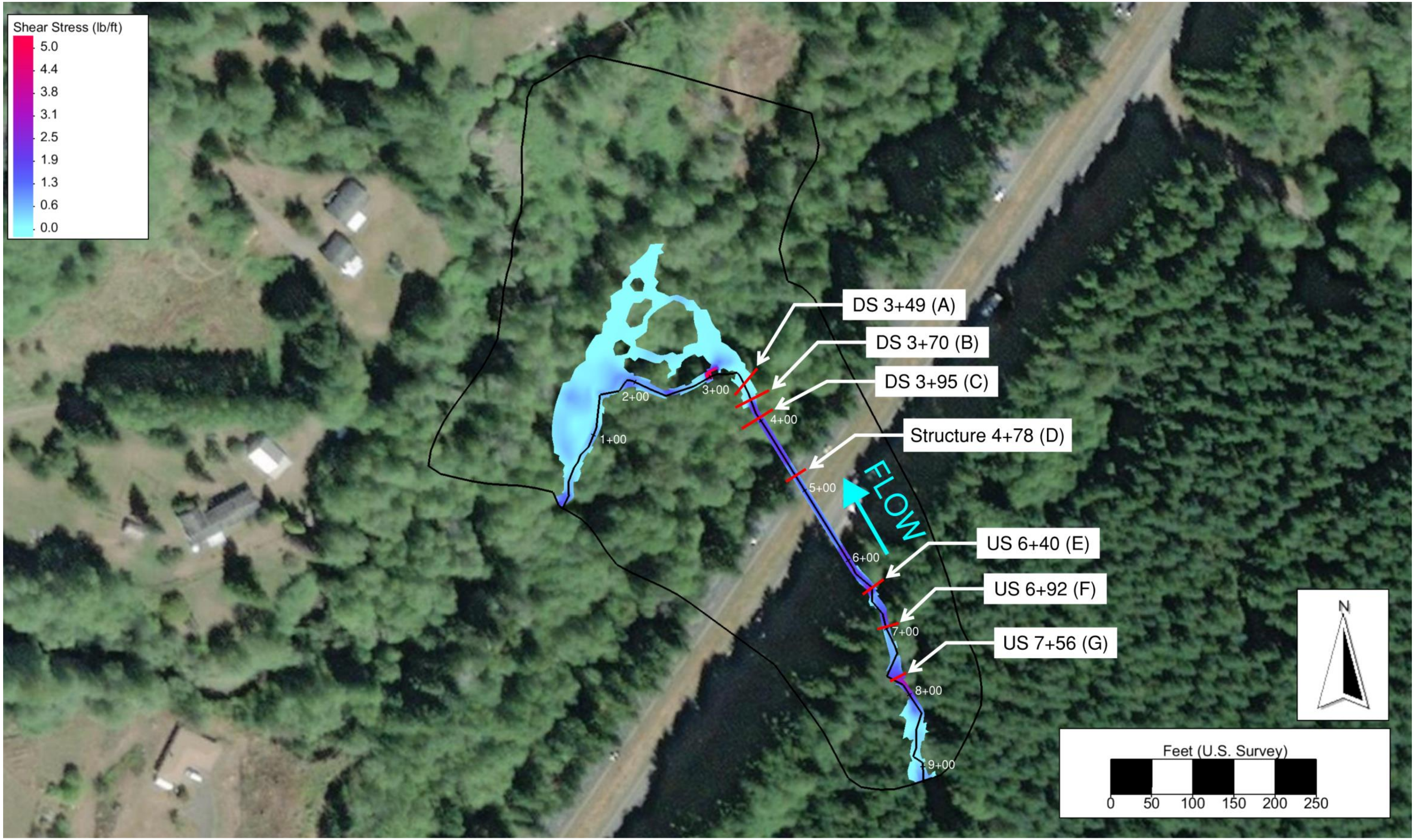


Figure H.20: Proposed conditions 2-year shear stress

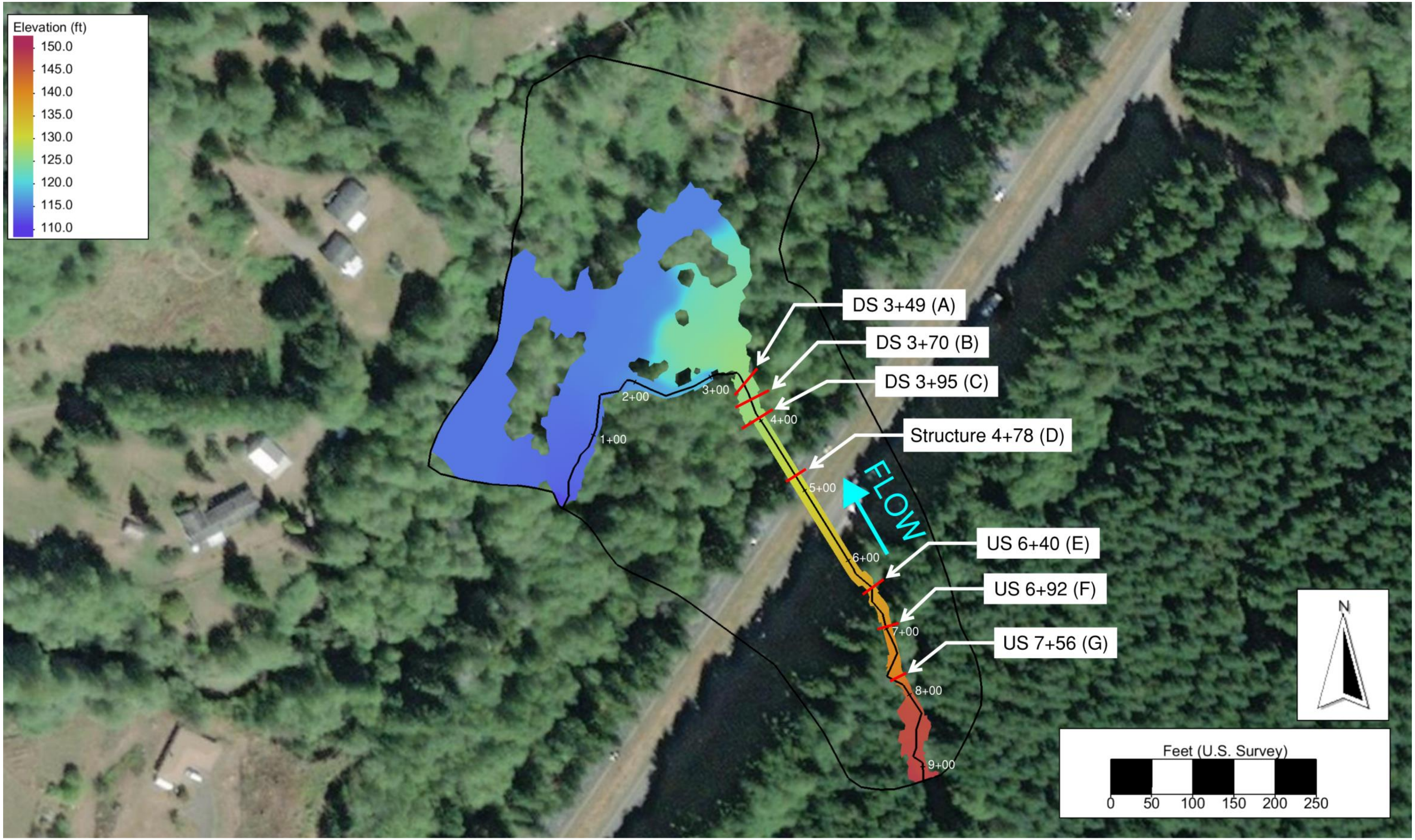


Figure H.21: Proposed conditions 100-year water surface elevation

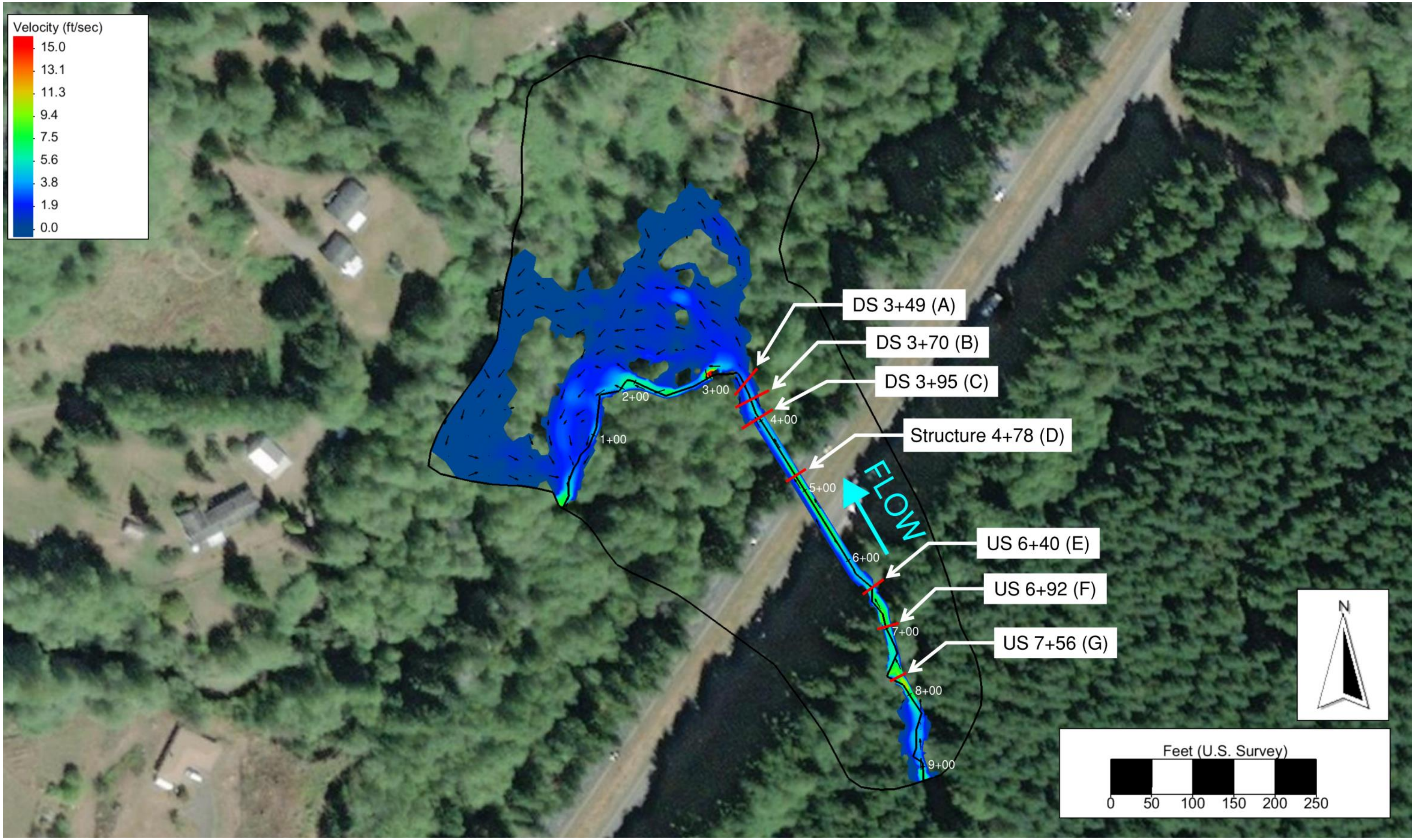


Figure H.22: Proposed conditions 100-year velocity

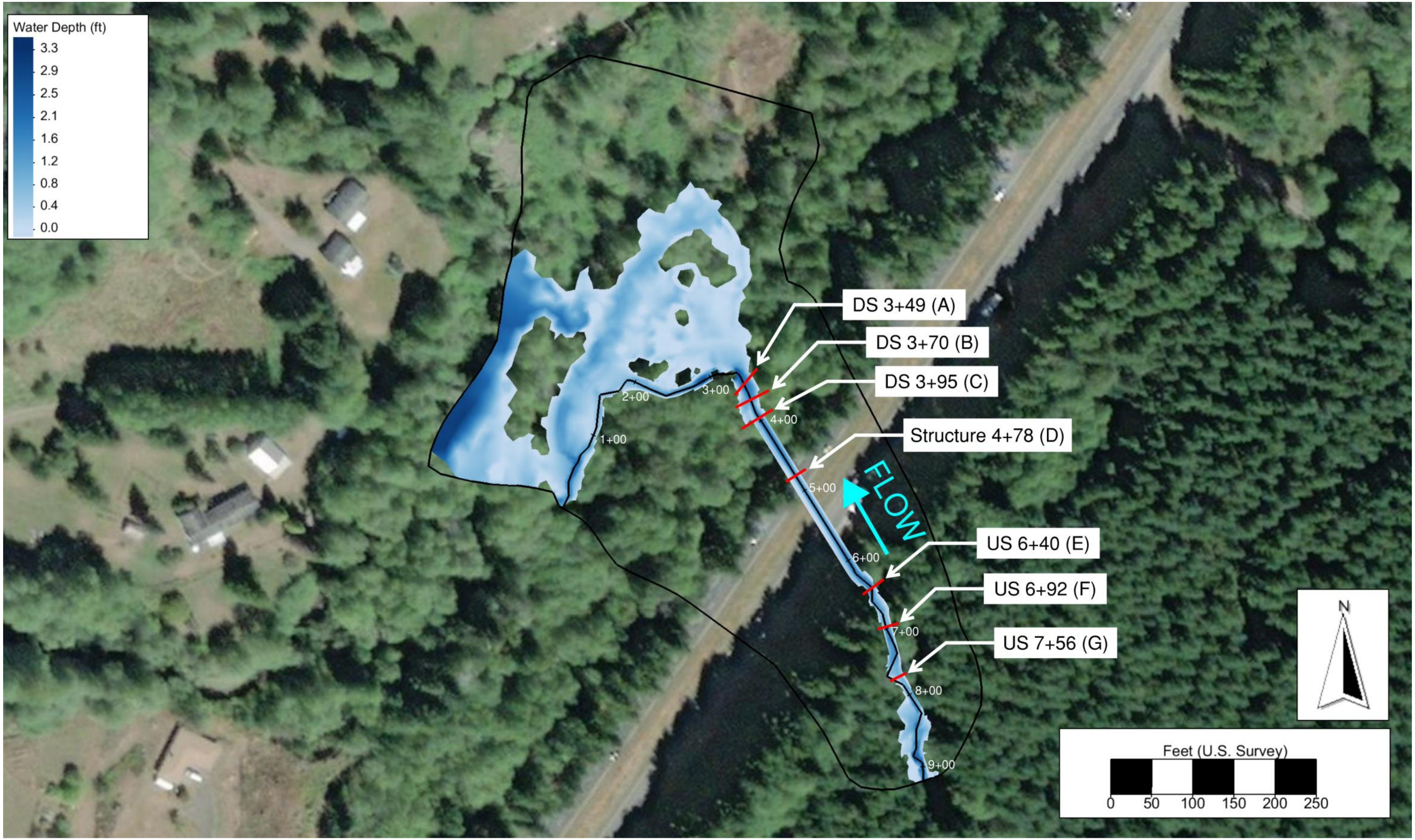


Figure H.23: Proposed conditions 100-year water depth

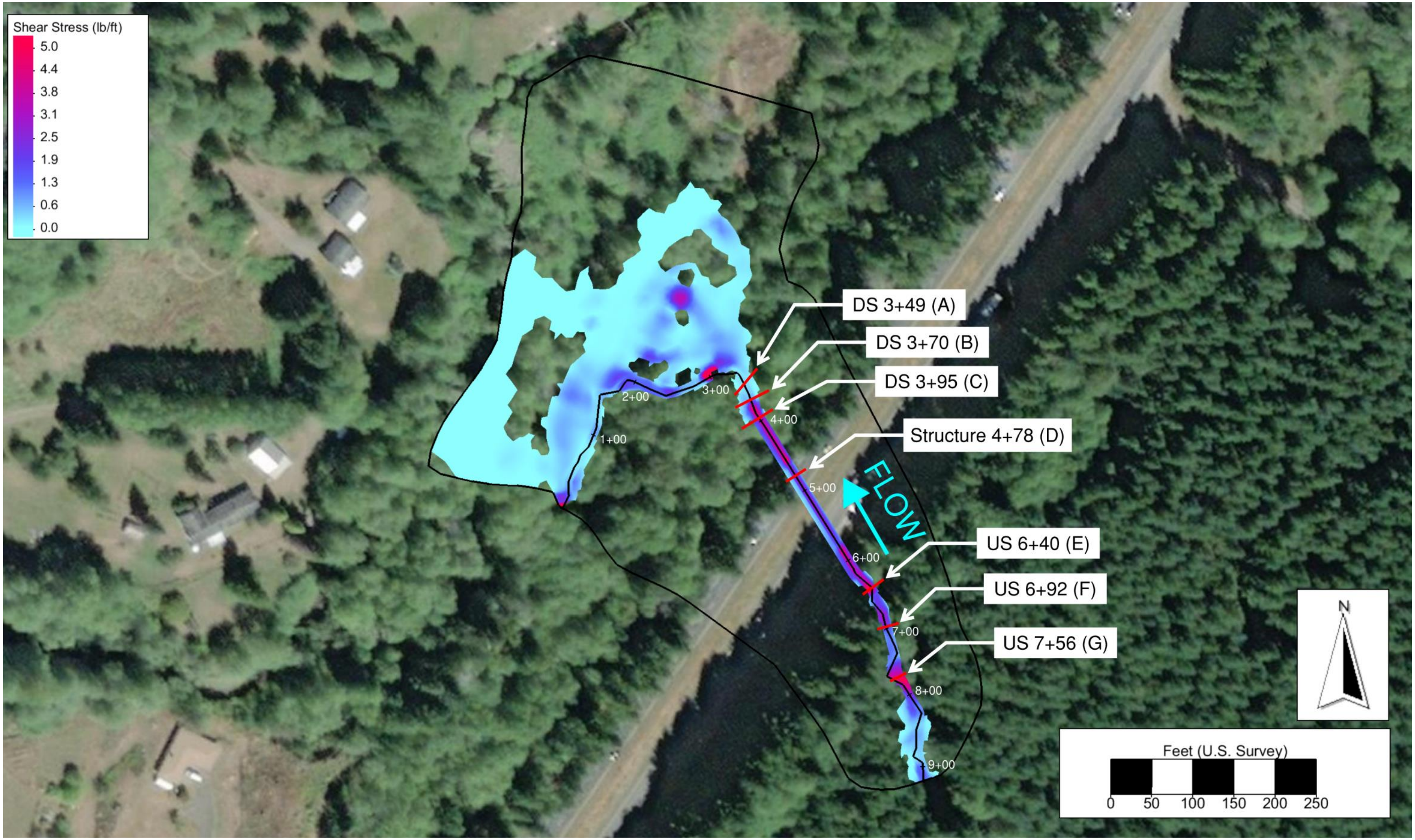


Figure H.24: Proposed conditions 100-year shear stress

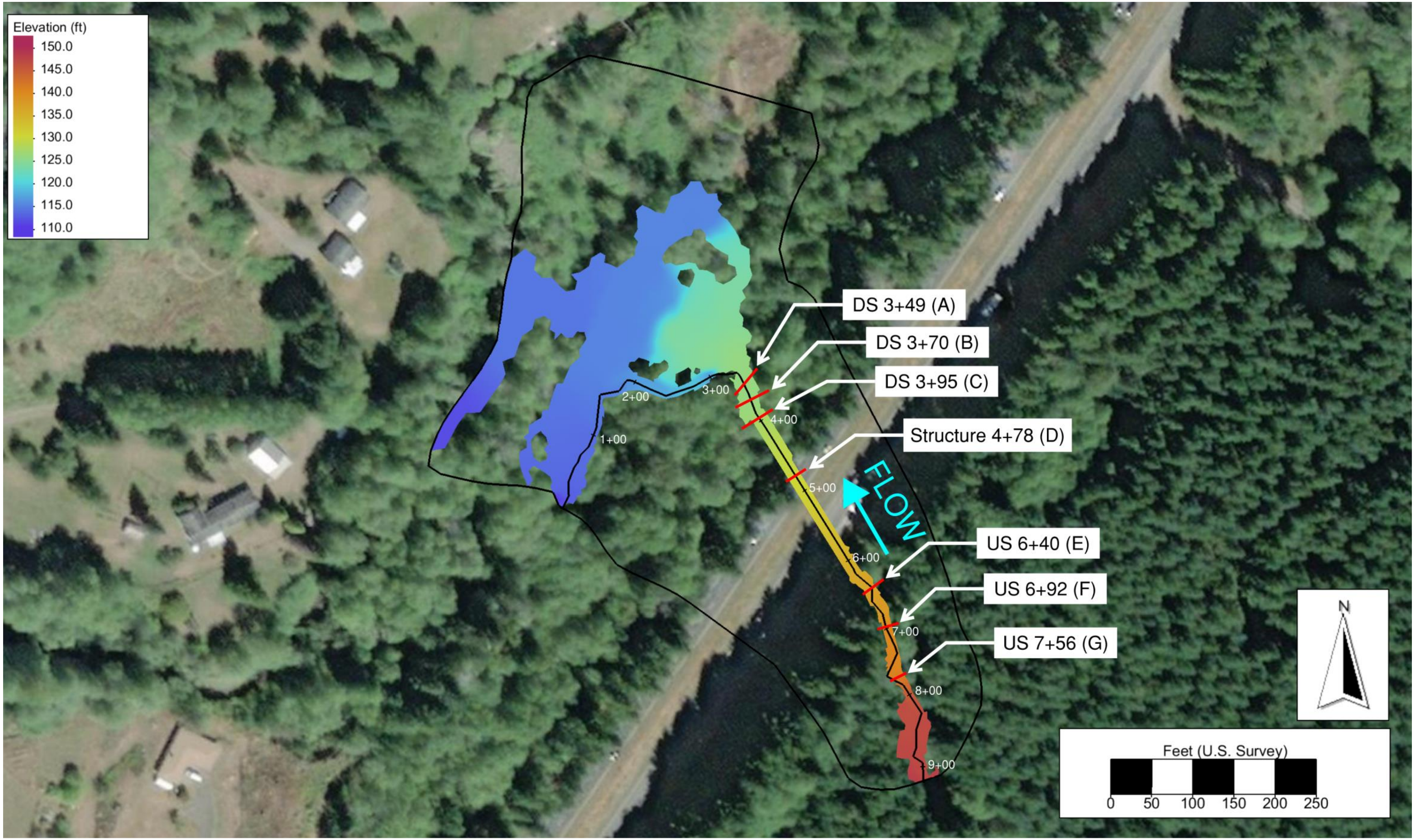


Figure H.25: Proposed conditions 500-year water surface elevation

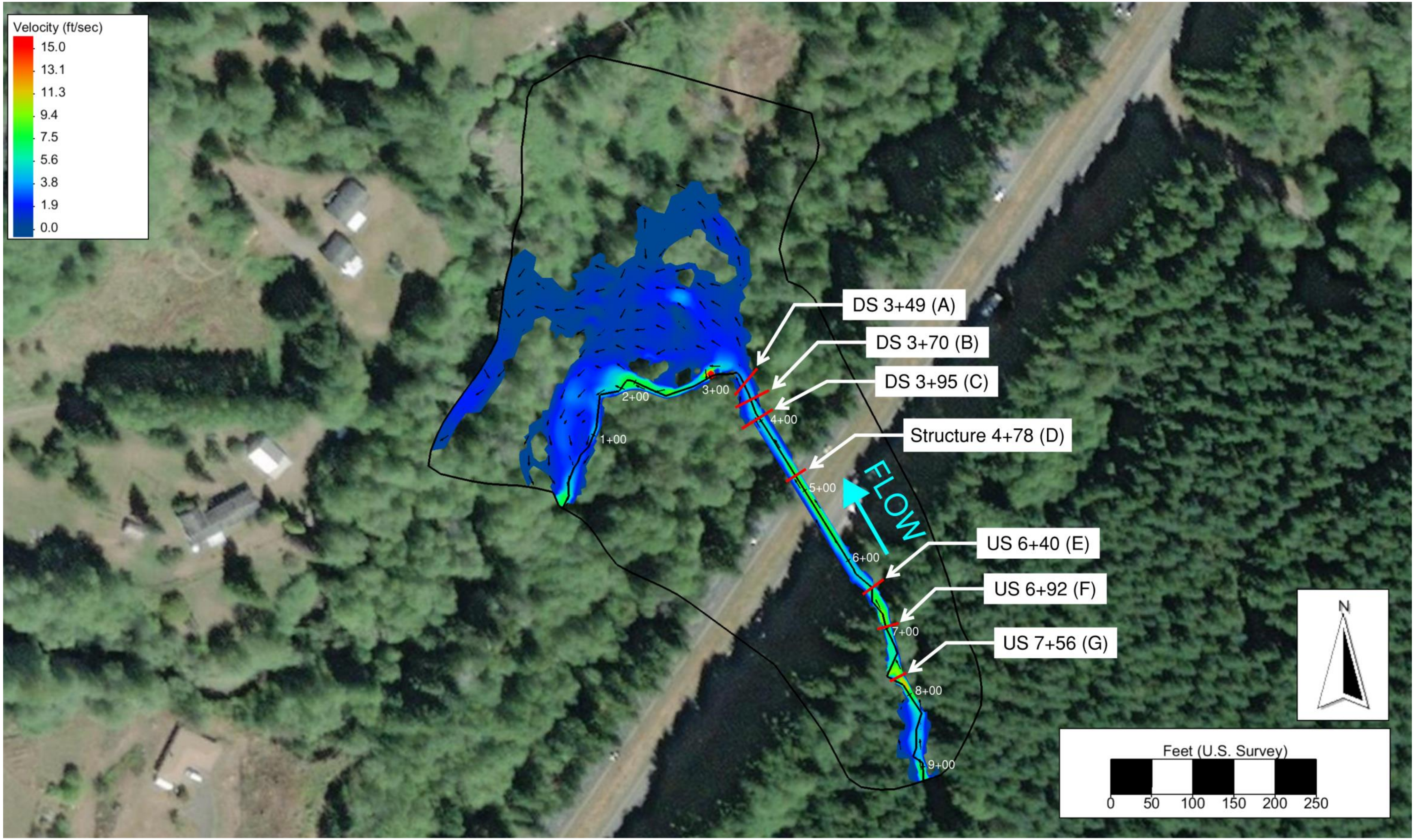


Figure H.26: Proposed conditions 500-year velocity

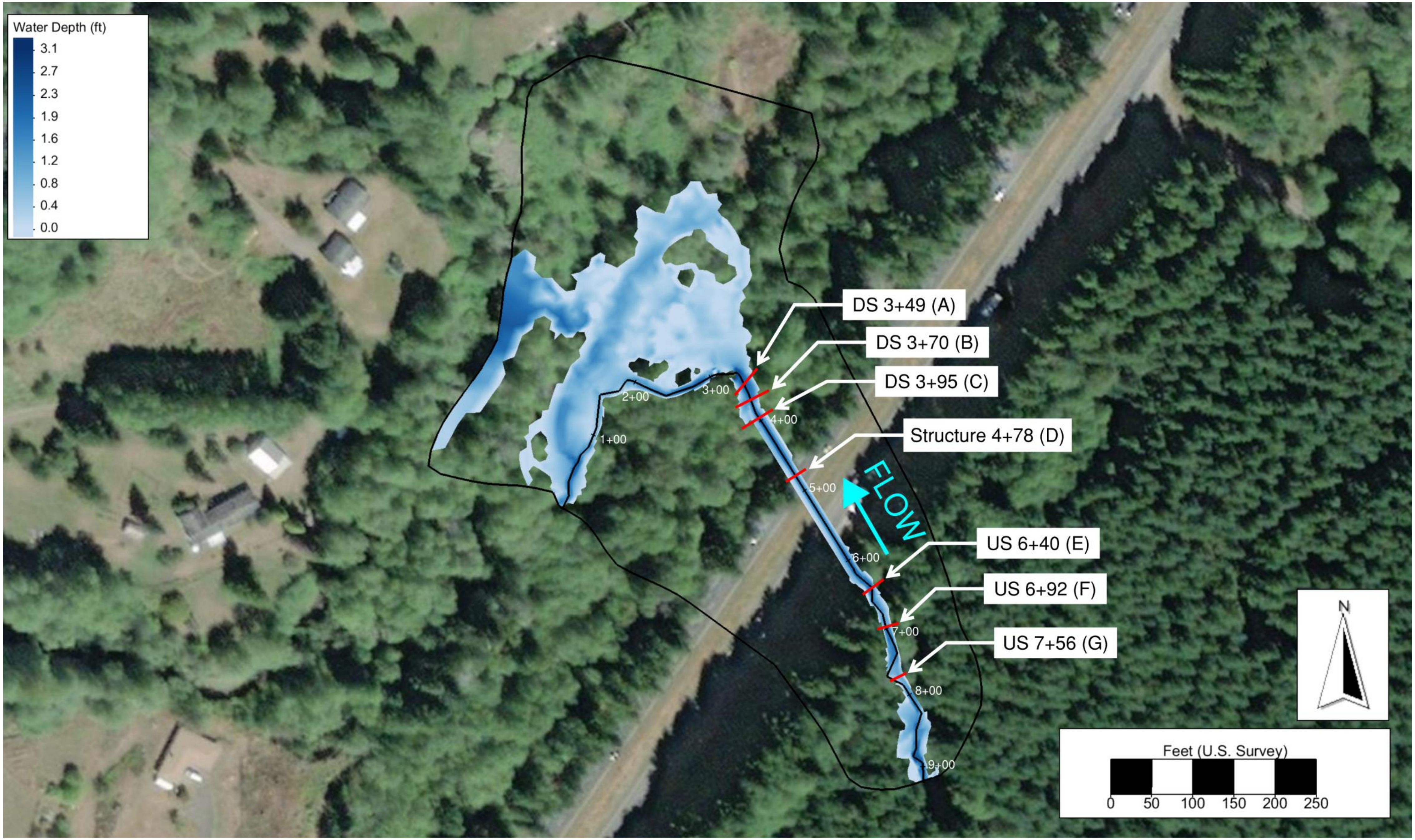


Figure H.27: Proposed conditions 500-year water depth

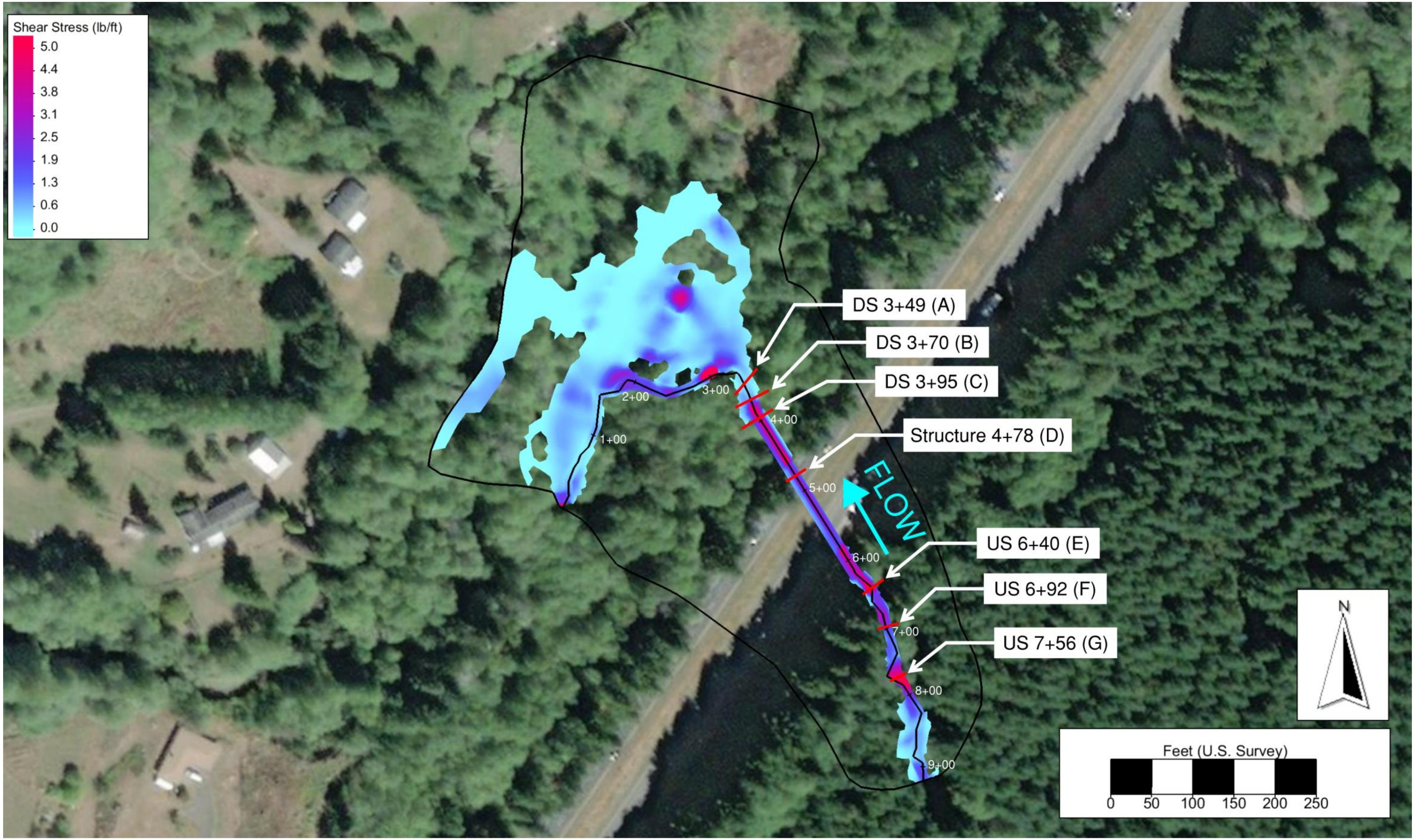


Figure H.28: Proposed conditions 500-year shear stress

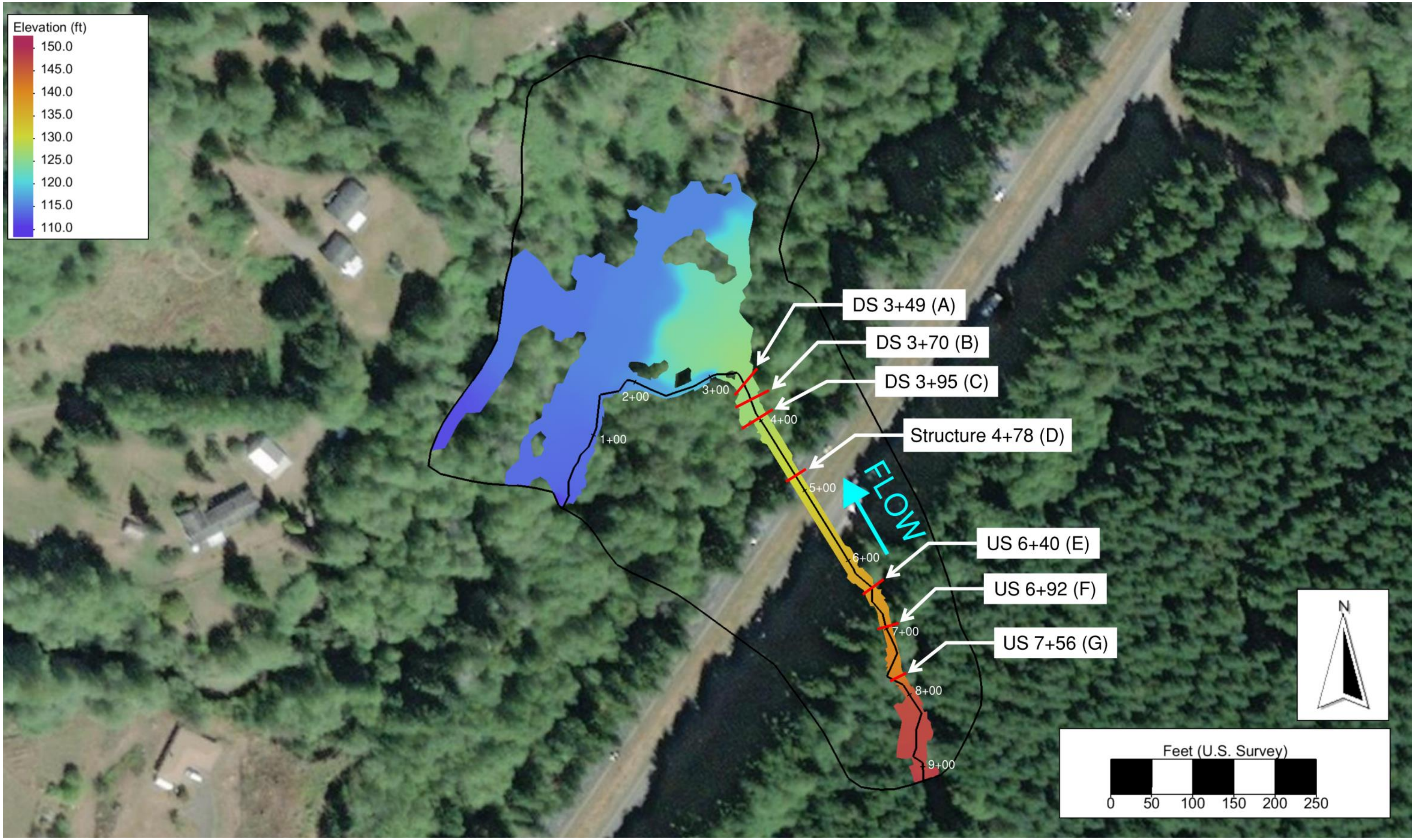


Figure H.29: Proposed conditions 2080 projected 100-year water surface elevation

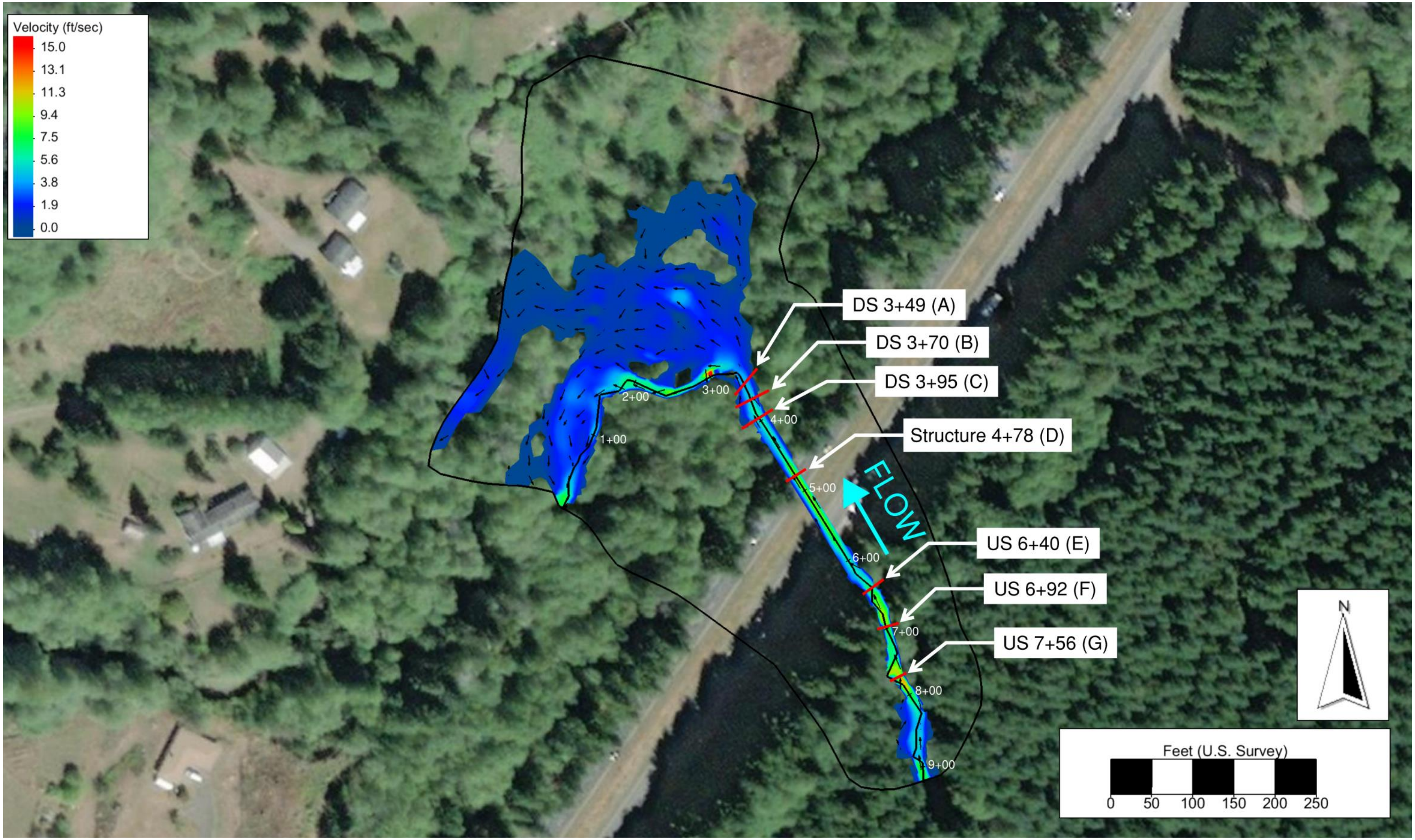


Figure H.30: Proposed conditions 2080 projected 100-year velocity

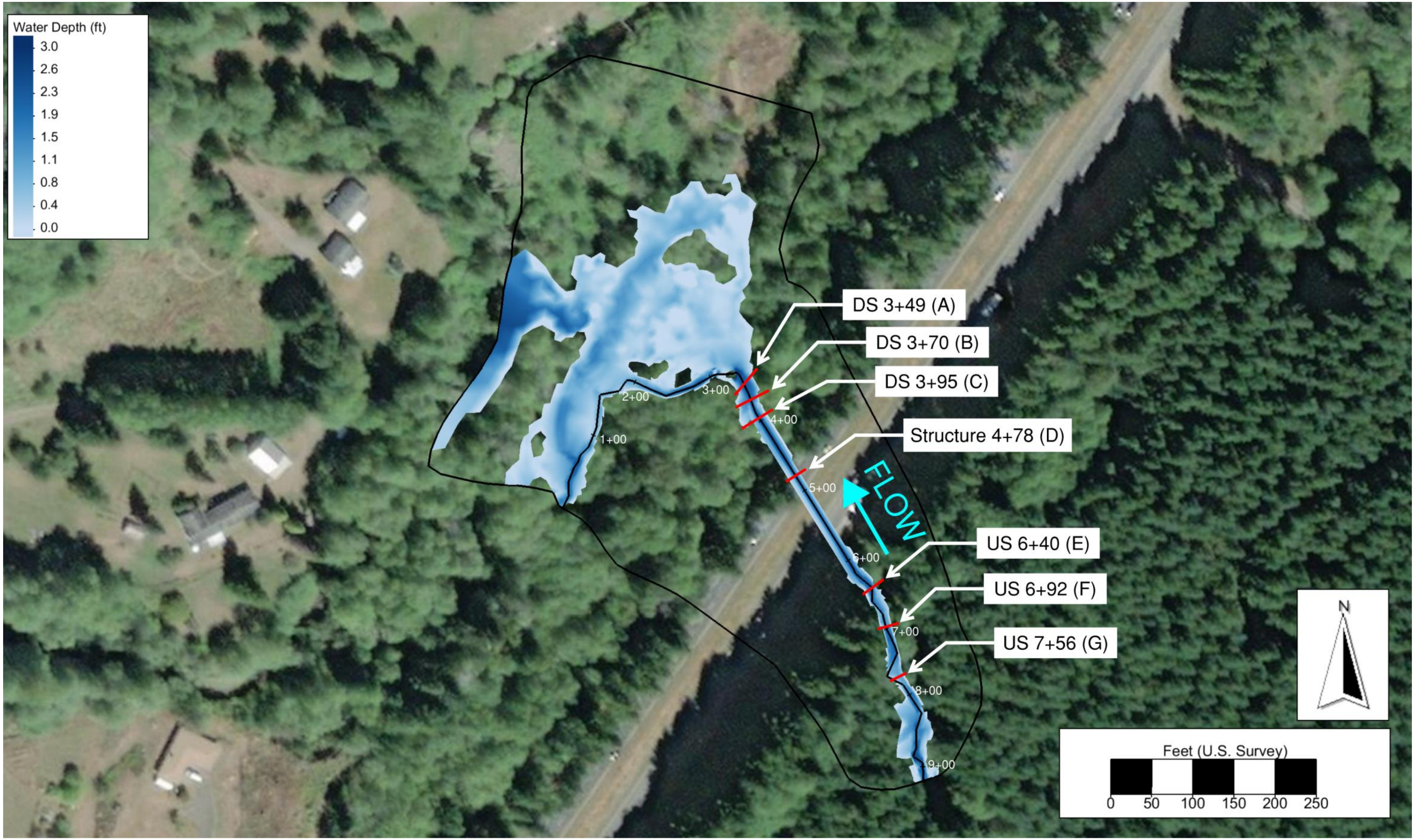


Figure H.31: Proposed conditions 2080 projected 100-year water depth

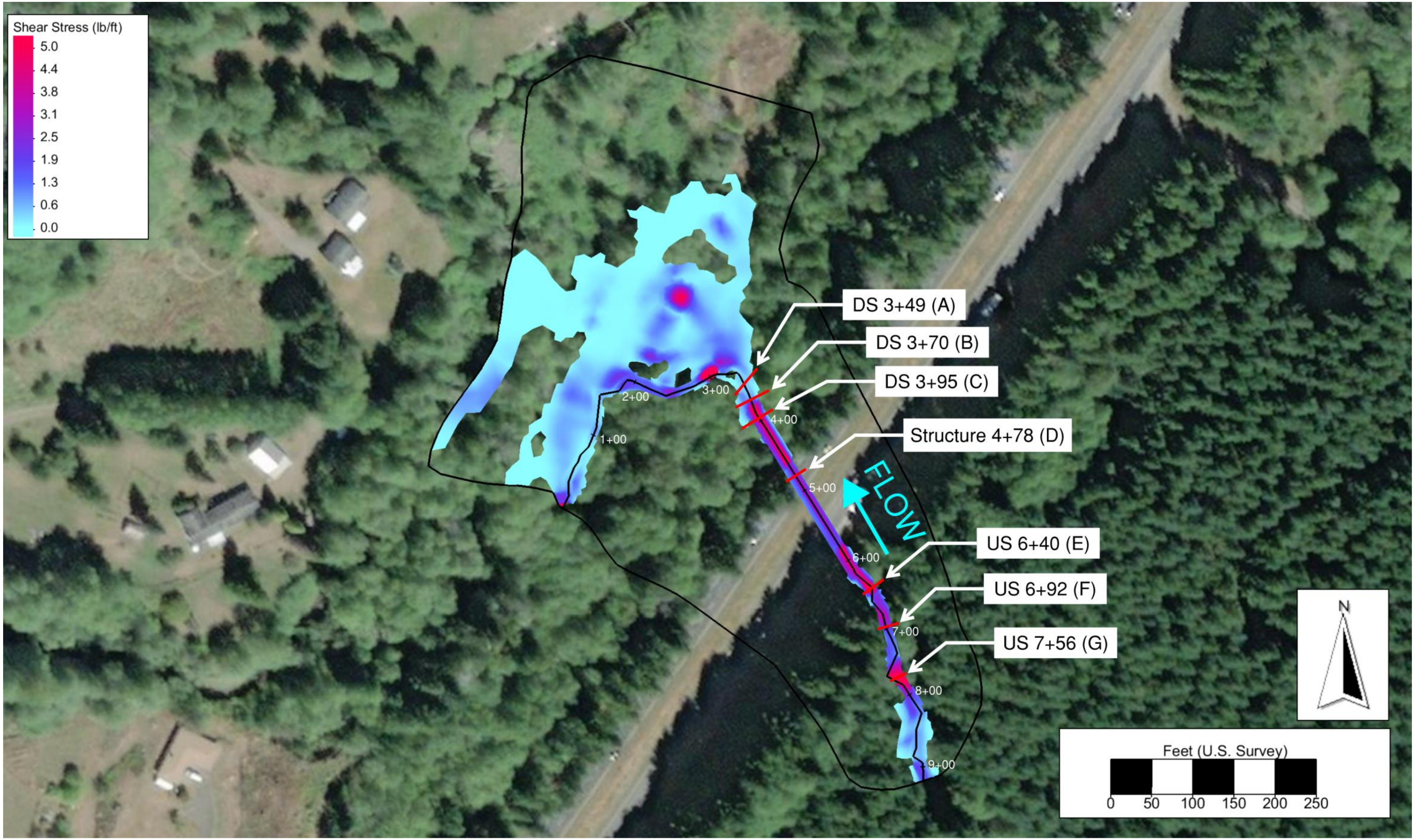


Figure H.32: Proposed conditions 2080 projected 100-year shear stress

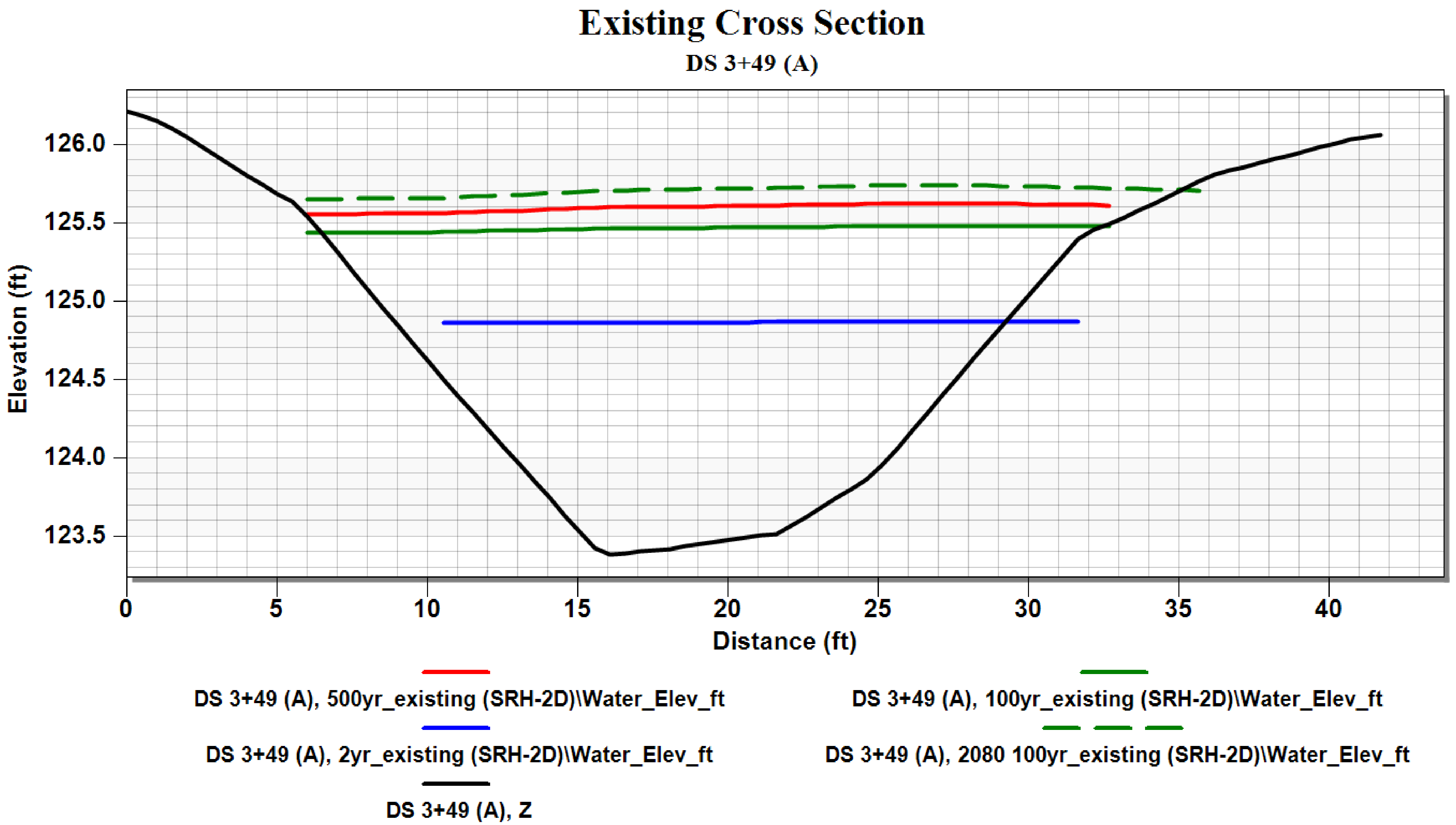


Figure H.33: Existing conditions cross section at downstream station 3+49 (A)

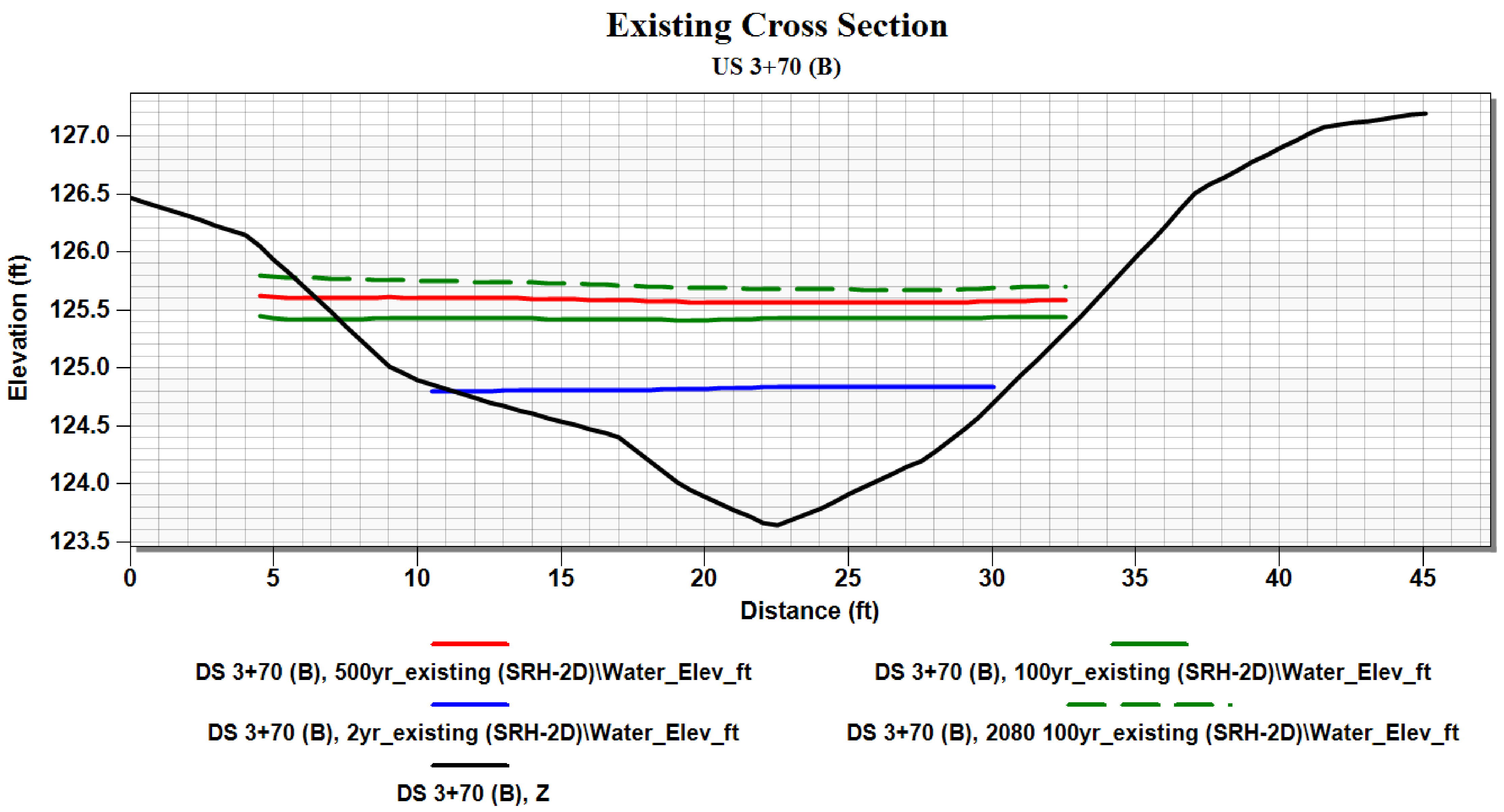


Figure H.34: Existing conditions cross section at downstream station 3+70 (B)

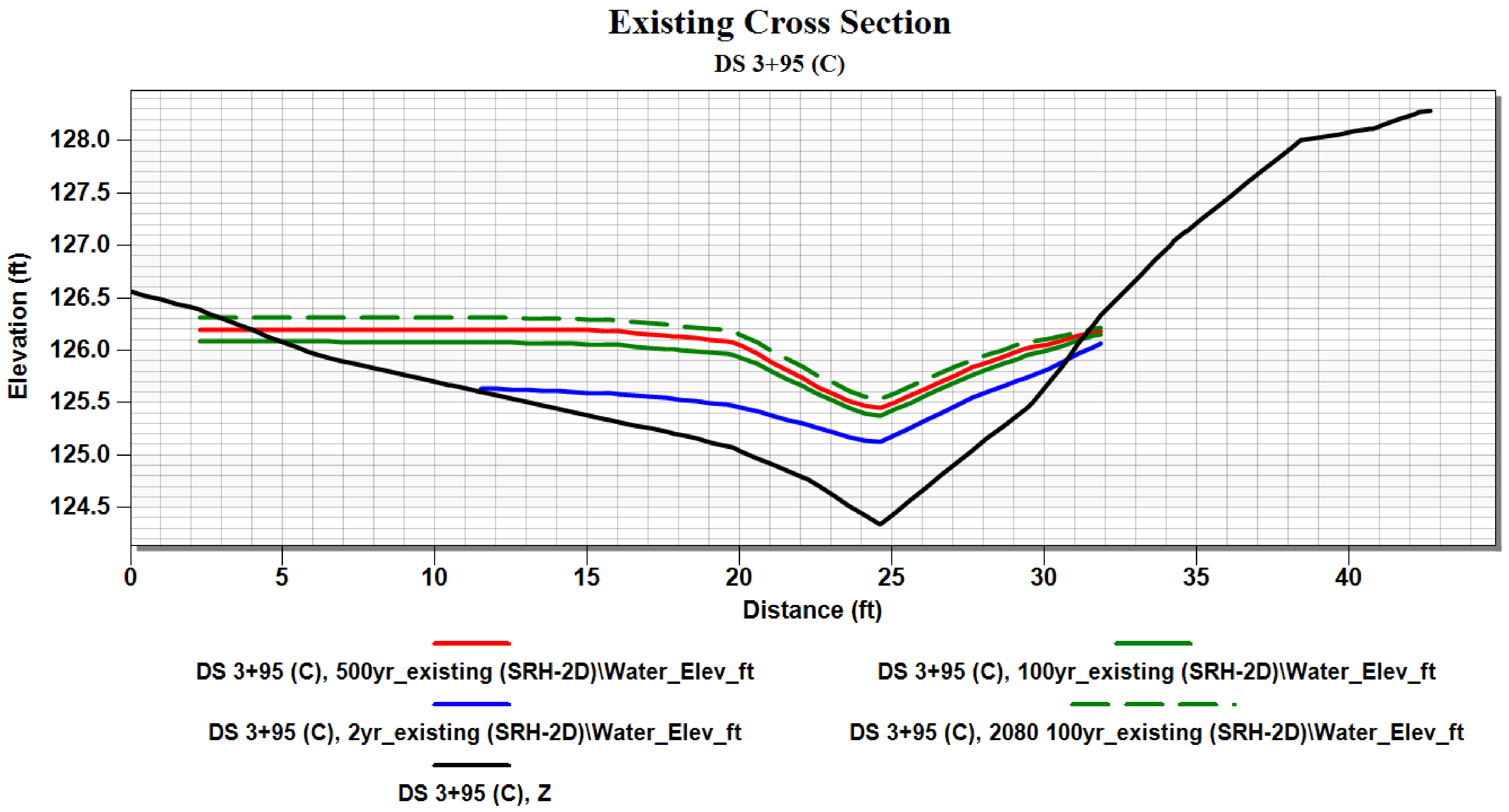


Figure H.35: Existing conditions cross section at downstream station 3+95 (C)

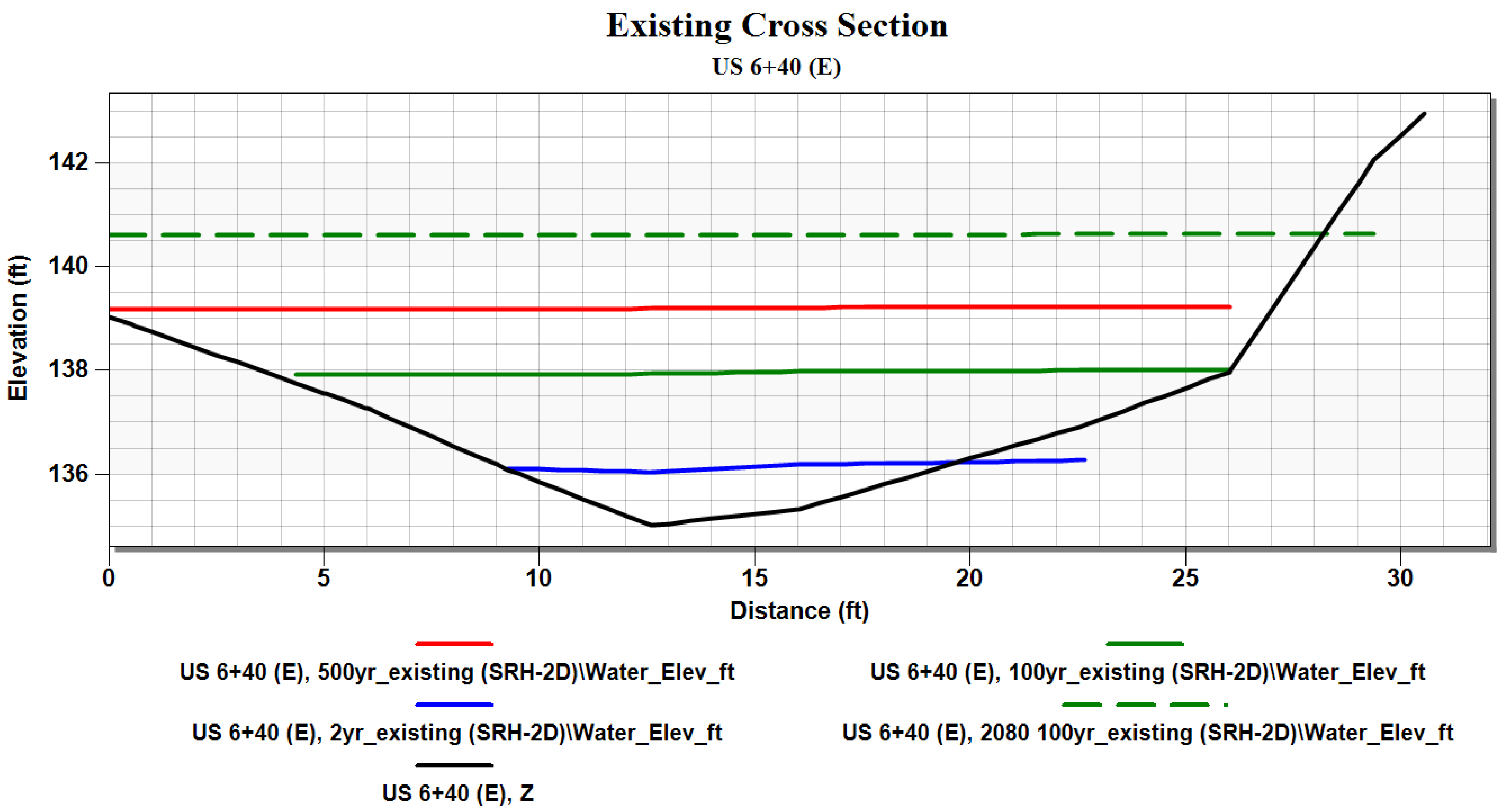


Figure H.36: Existing conditions cross section at upstream station 6+40 (E)

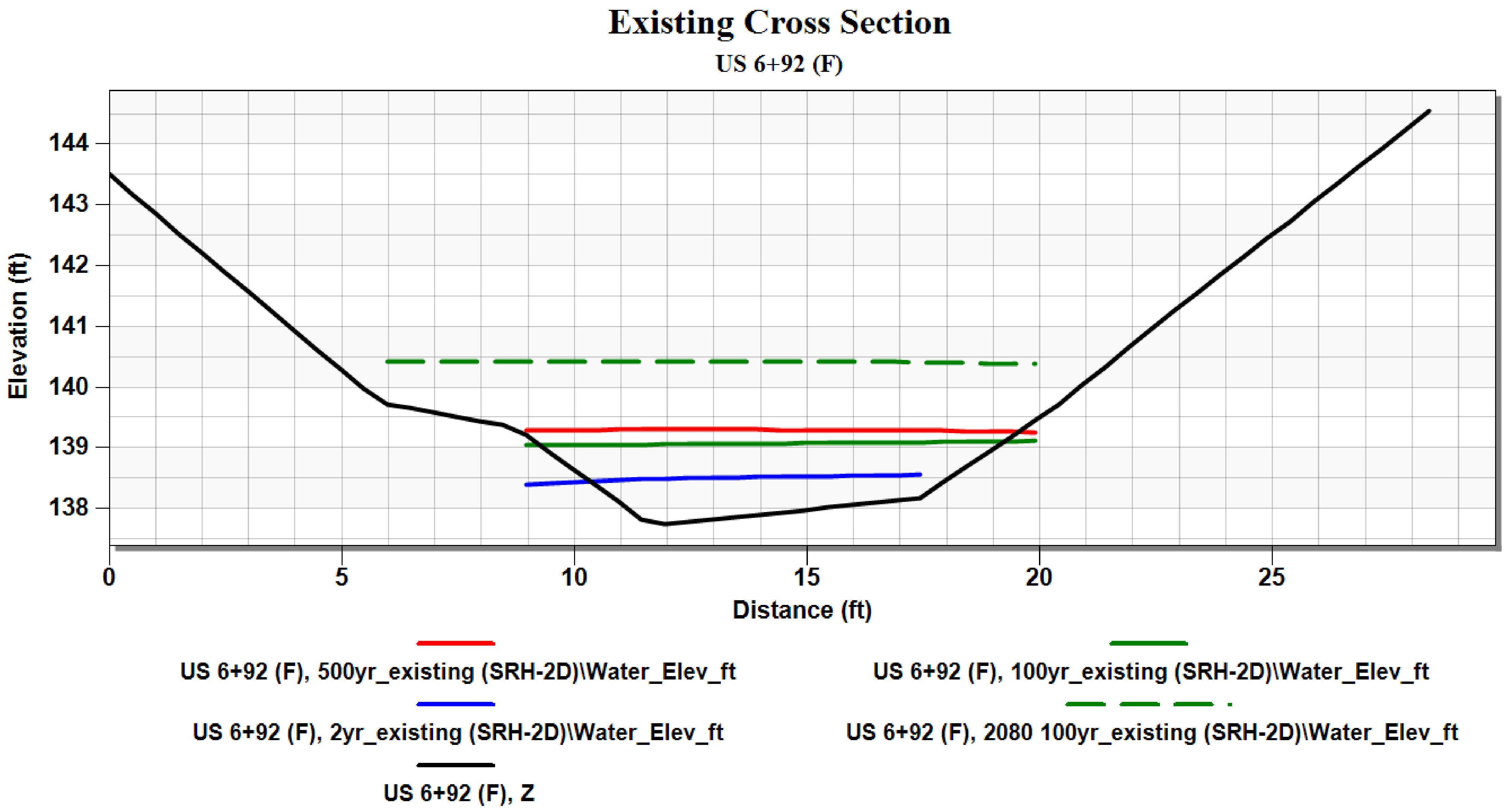


Figure H.37: Existing conditions cross section at upstream station 6+92 (F)

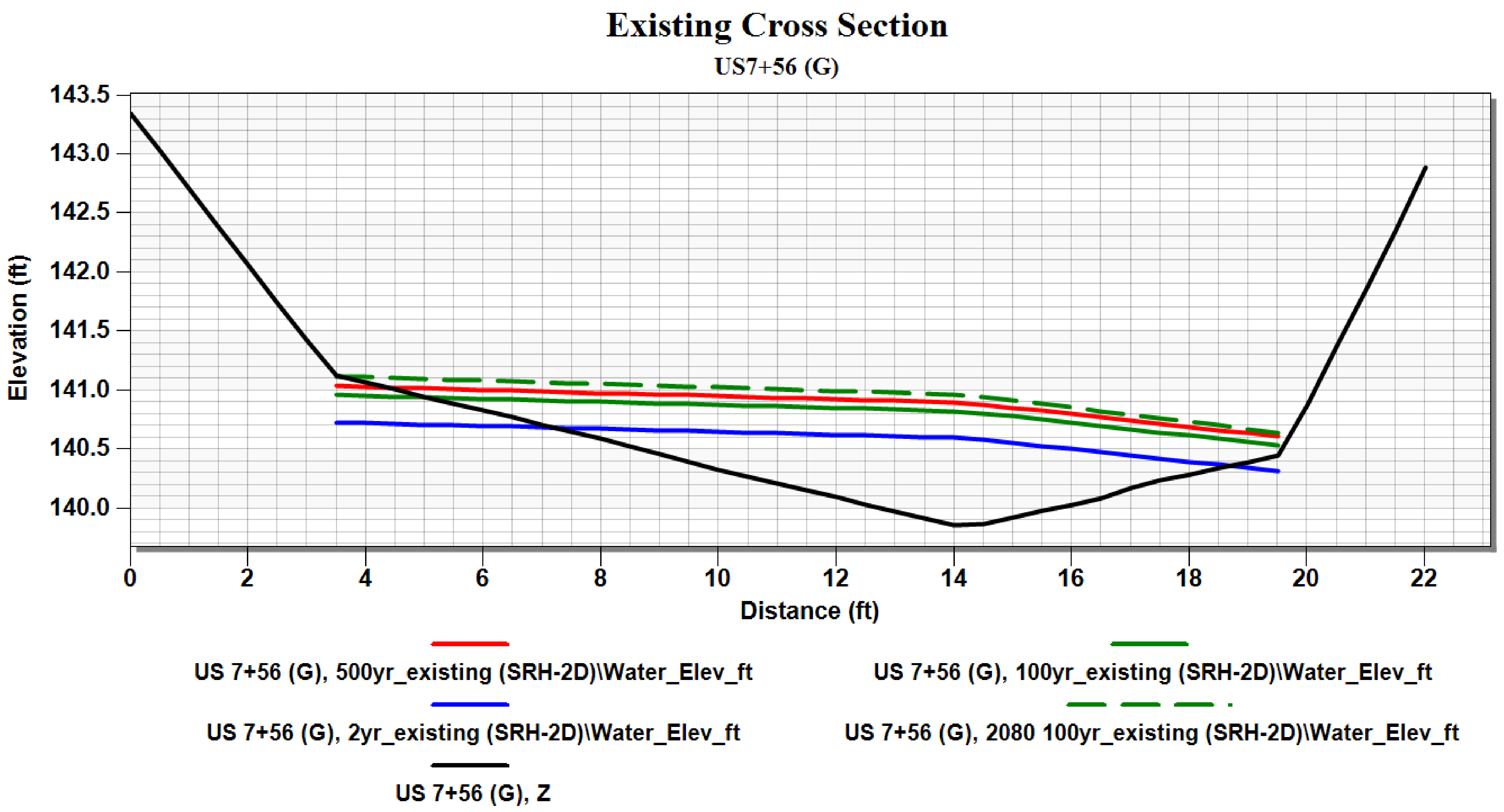


Figure H.38: Existing conditions cross section at upstream station 7+56 (G)

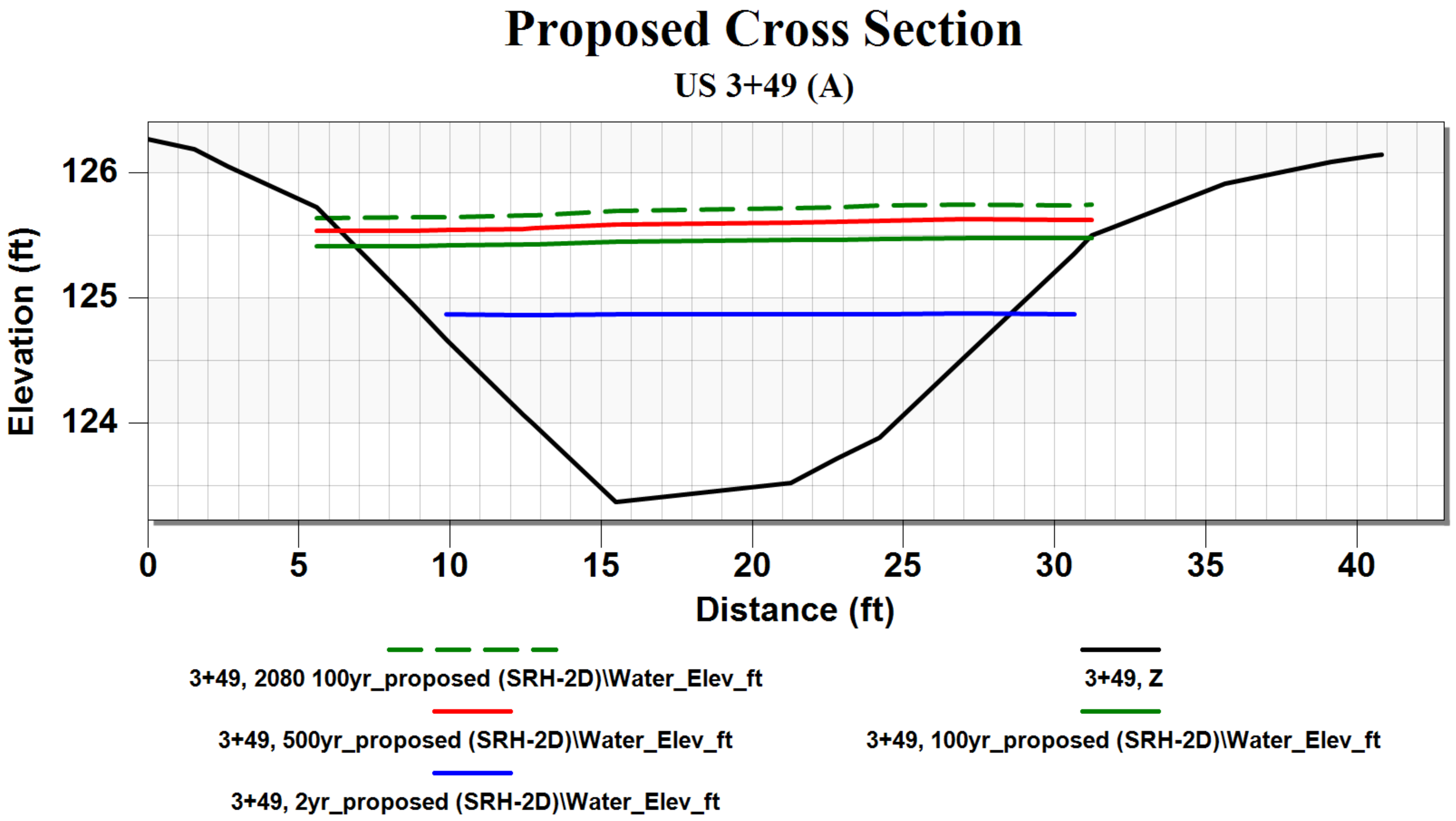


Figure H.39: Proposed conditions cross section at downstream station 3+49 (A)

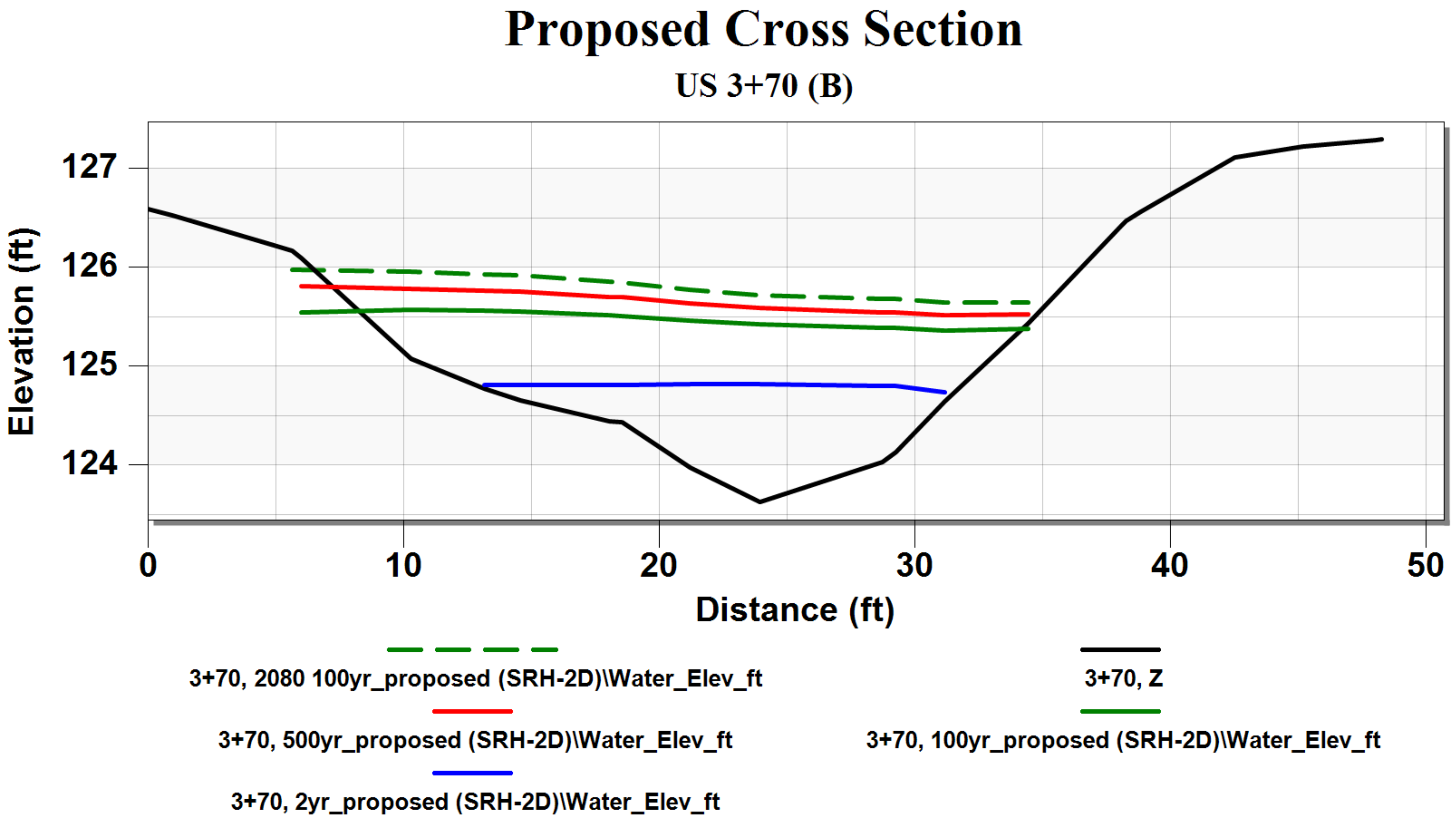


Figure H.40: Proposed conditions cross section at downstream station 3+70 (B)

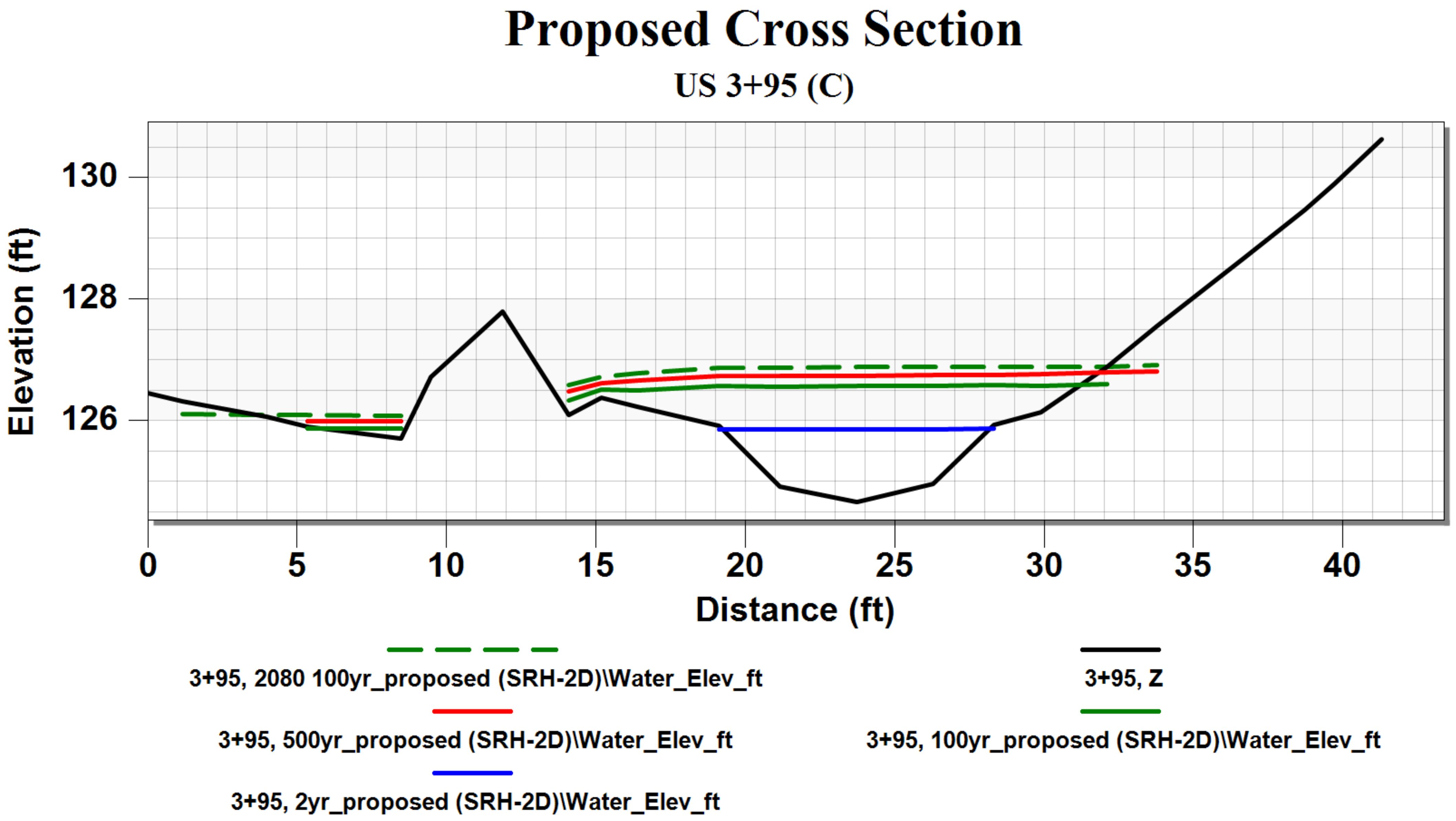


Figure H.41: Proposed conditions cross section at downstream station 3+95 (C)

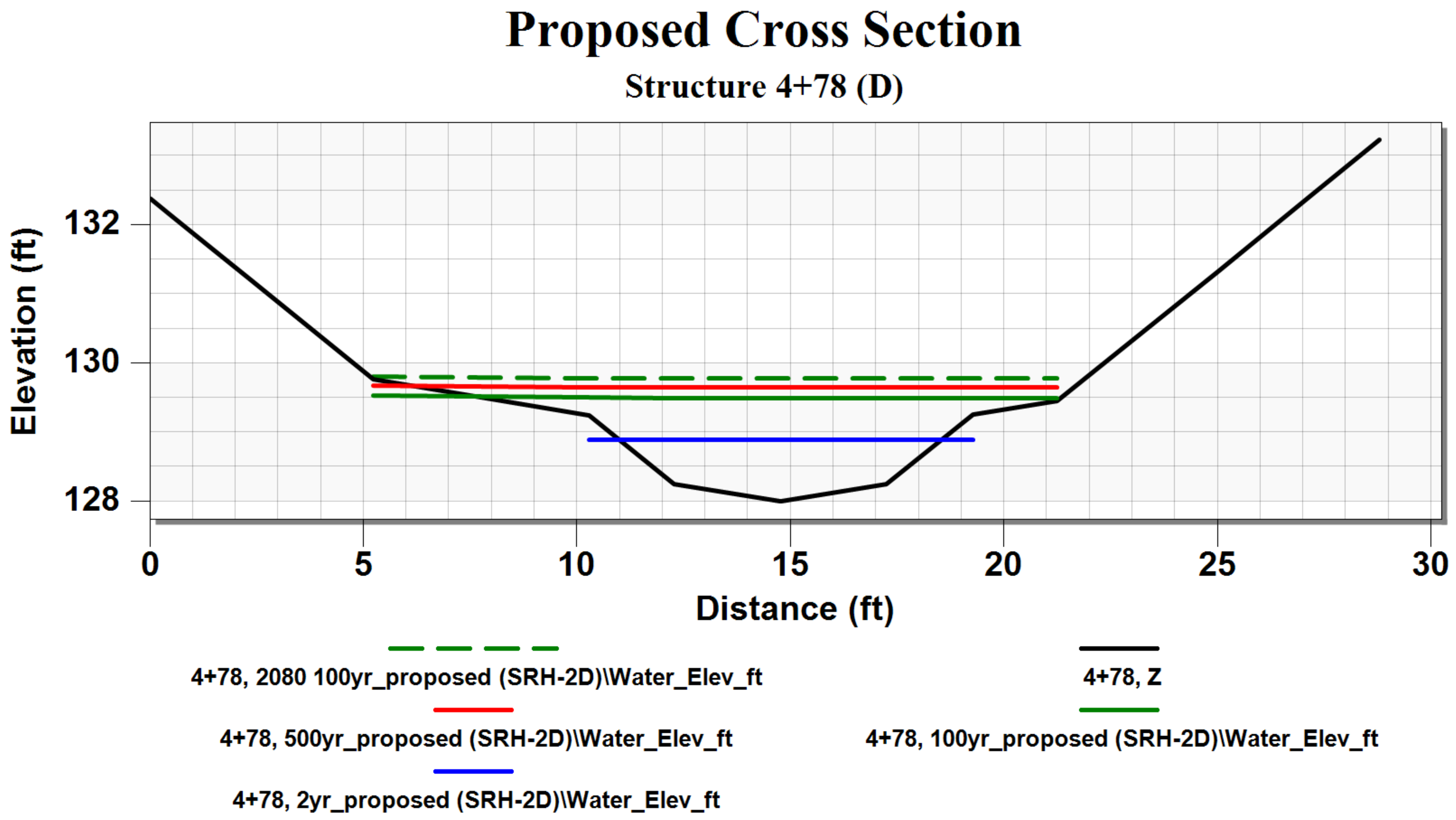


Figure H.42: Proposed conditions cross section at structure station 4+78 (D)

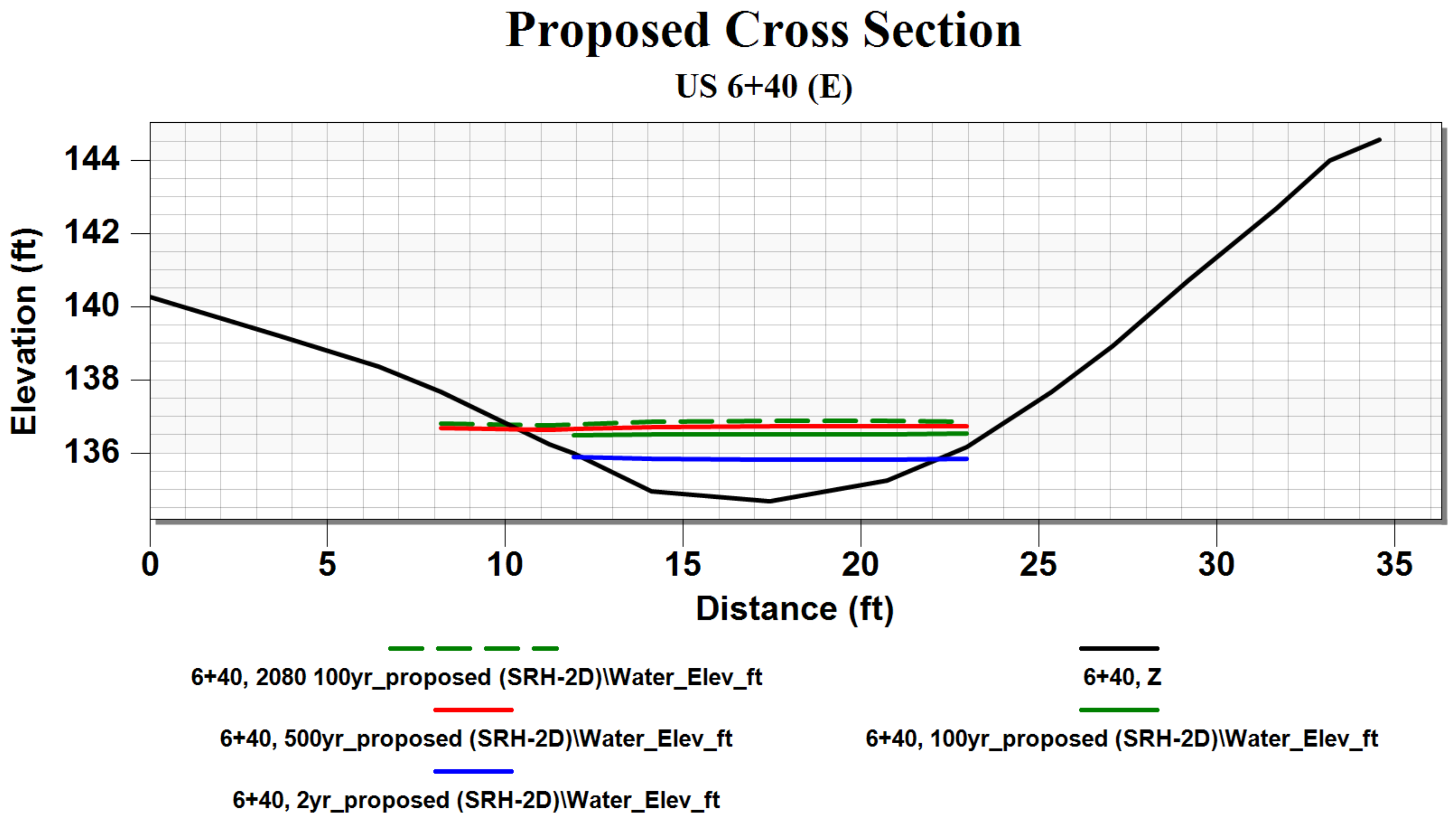


Figure H.43: Proposed conditions cross section at upstream station 6+40 (E)

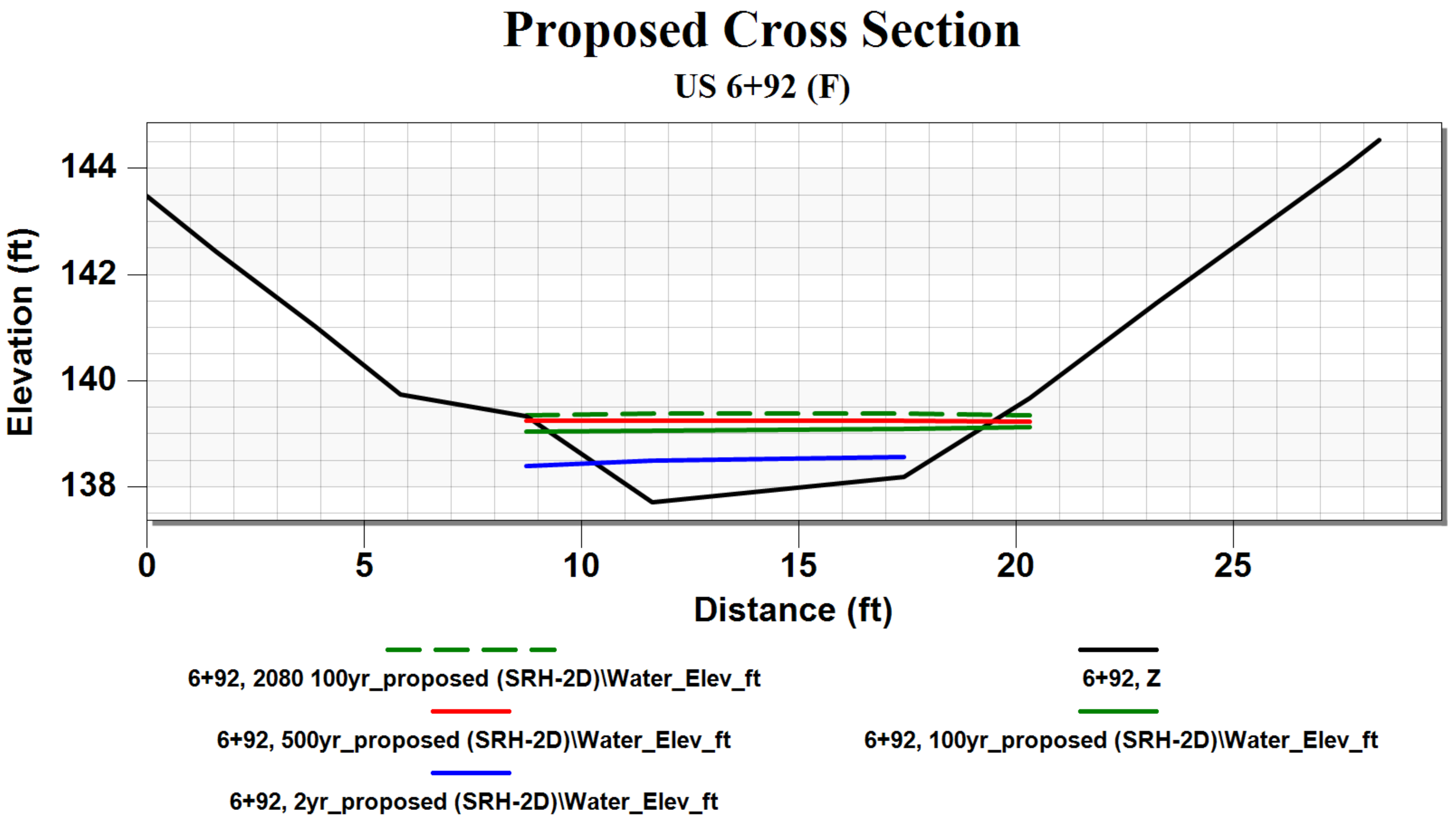


Figure H.44: Proposed conditions cross section at upstream station 6+92 (F)

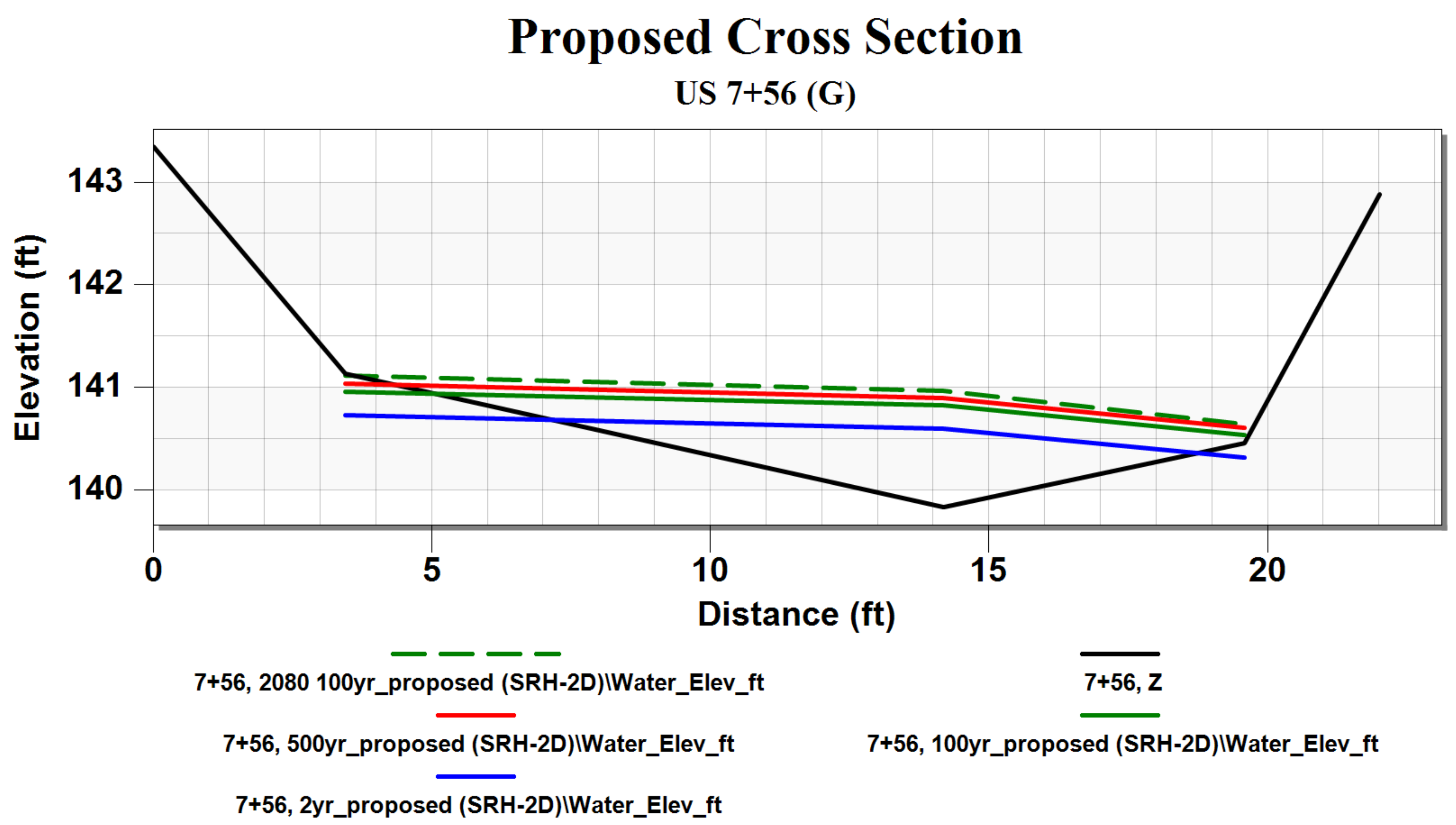


Figure H.45: Proposed conditions cross section at upstream station 7+56 (G)

Appendix I: SRH-2D Model Stability and Continuity

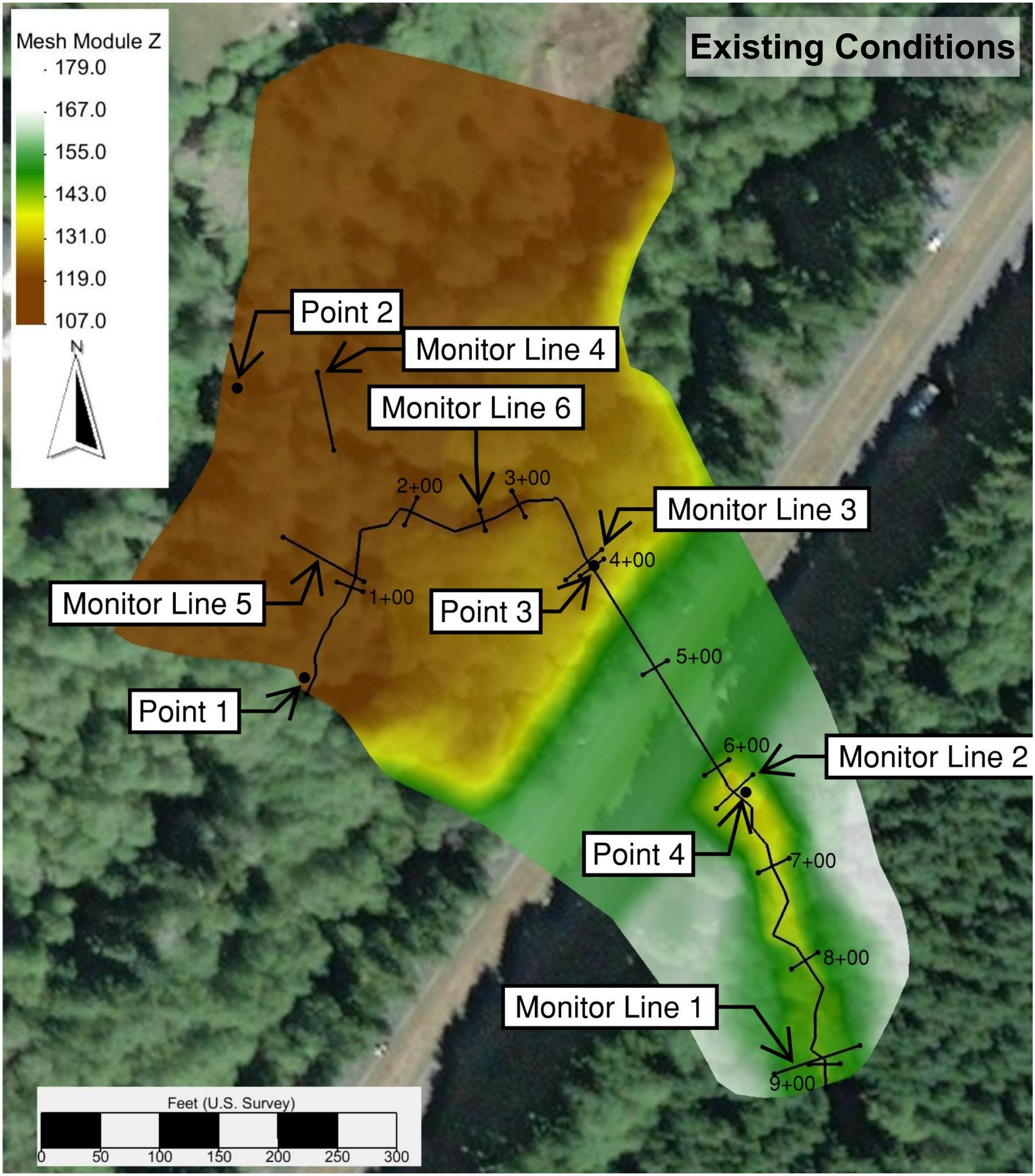


Figure I.1: Locations for existing conditions monitor lines and points

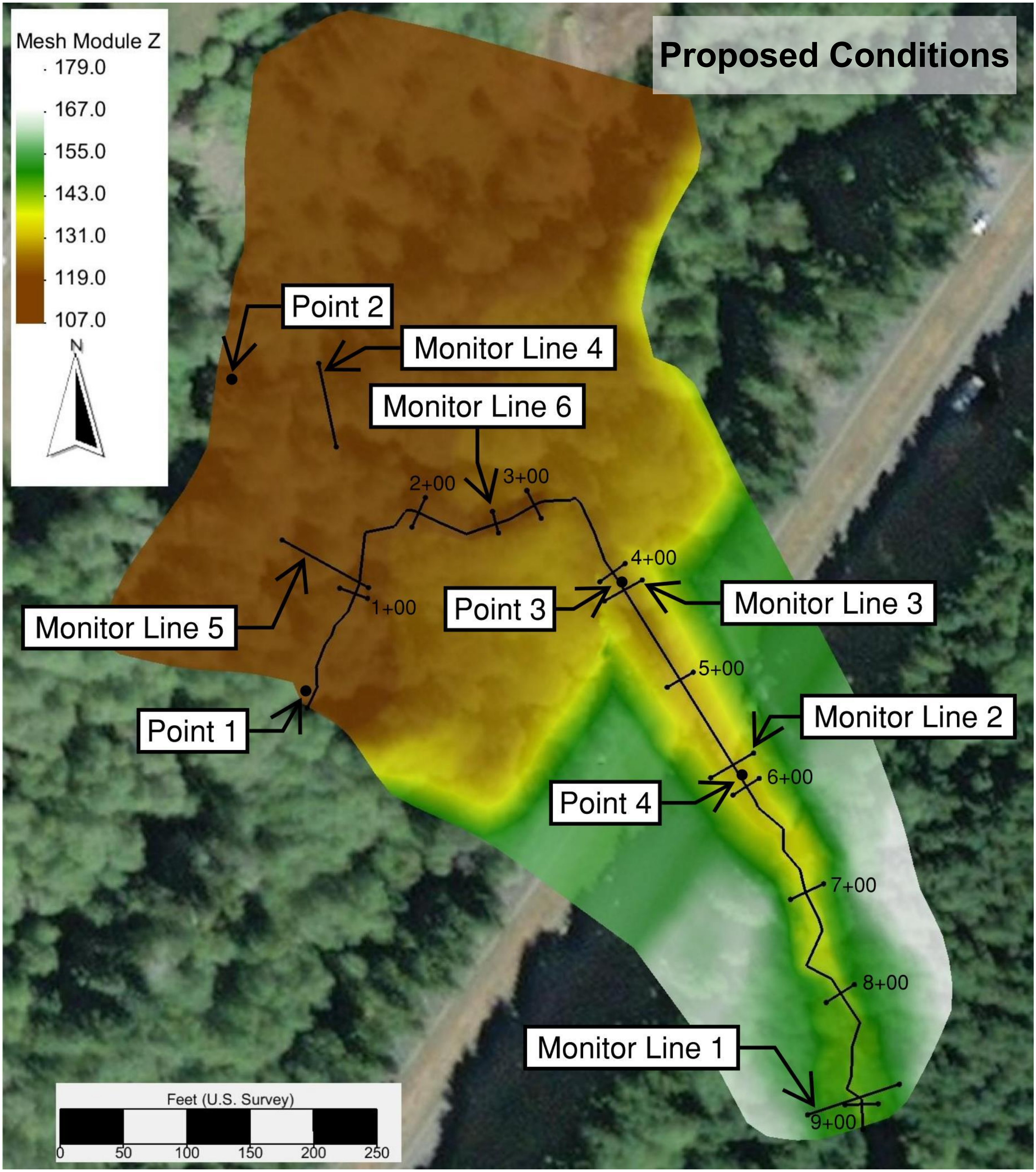


Figure I.2: Locations for proposed conditions monitor lines and points

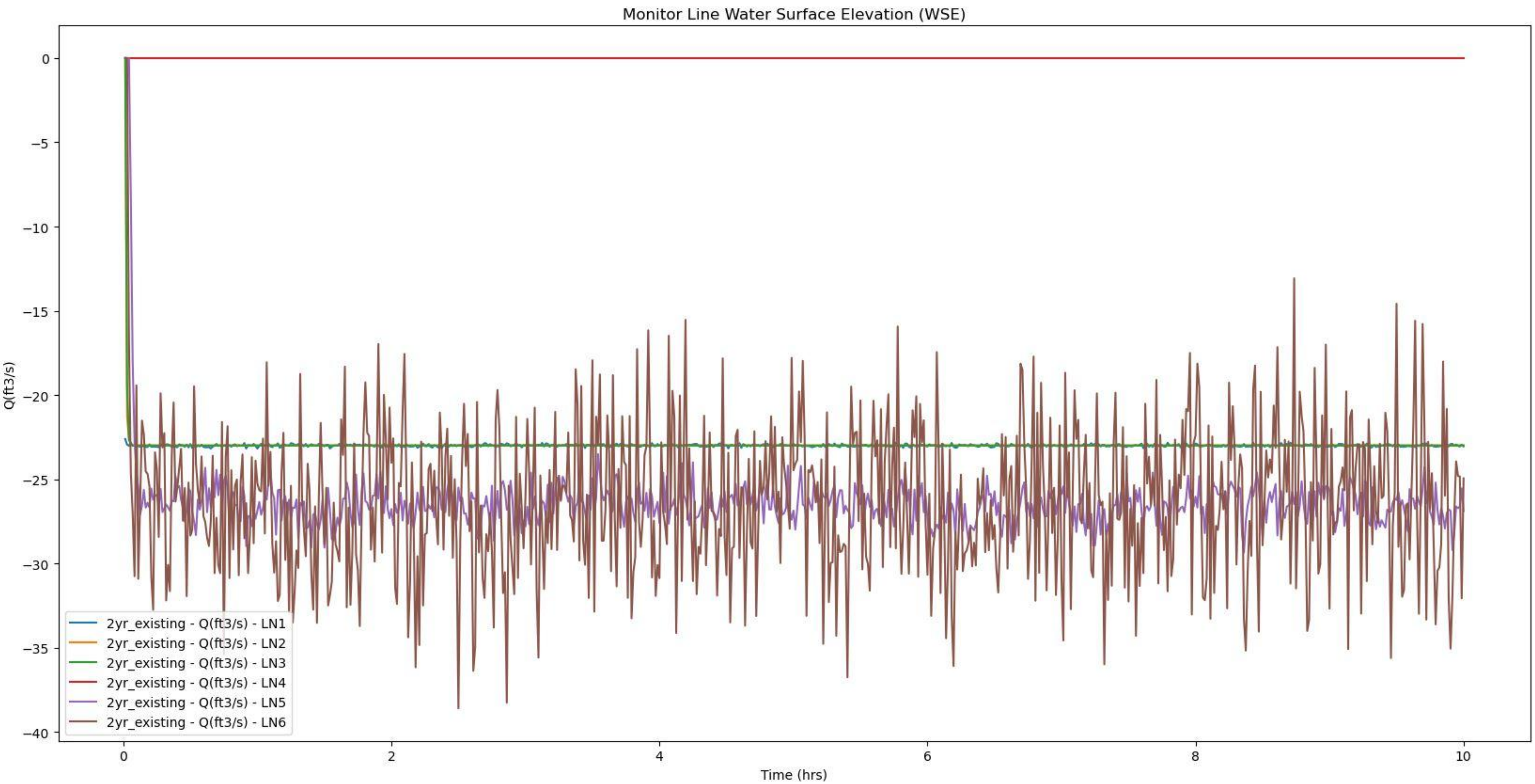


Figure I.3: Existing 2-year monitor lines

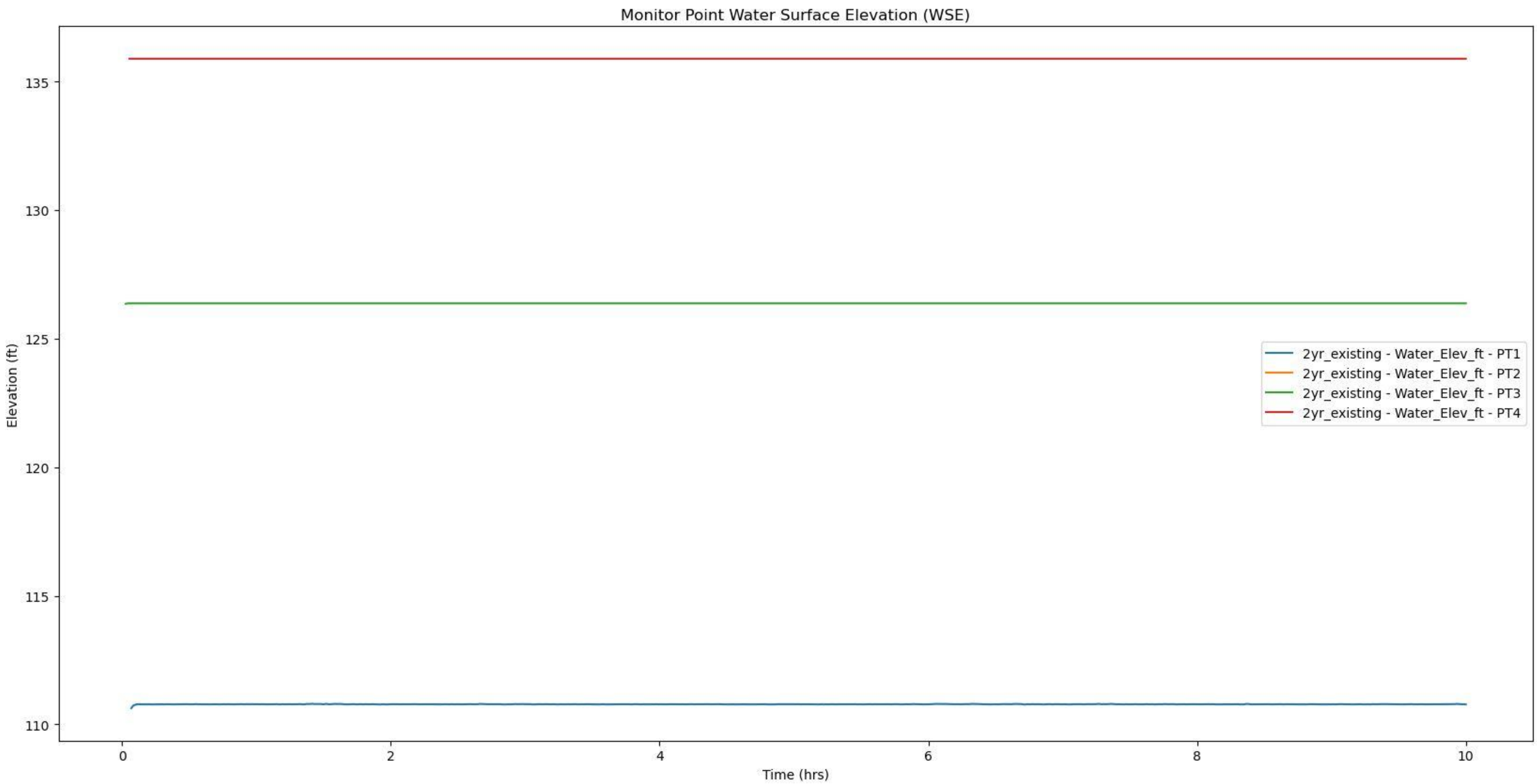


Figure I.4: Existing 2-year monitor points

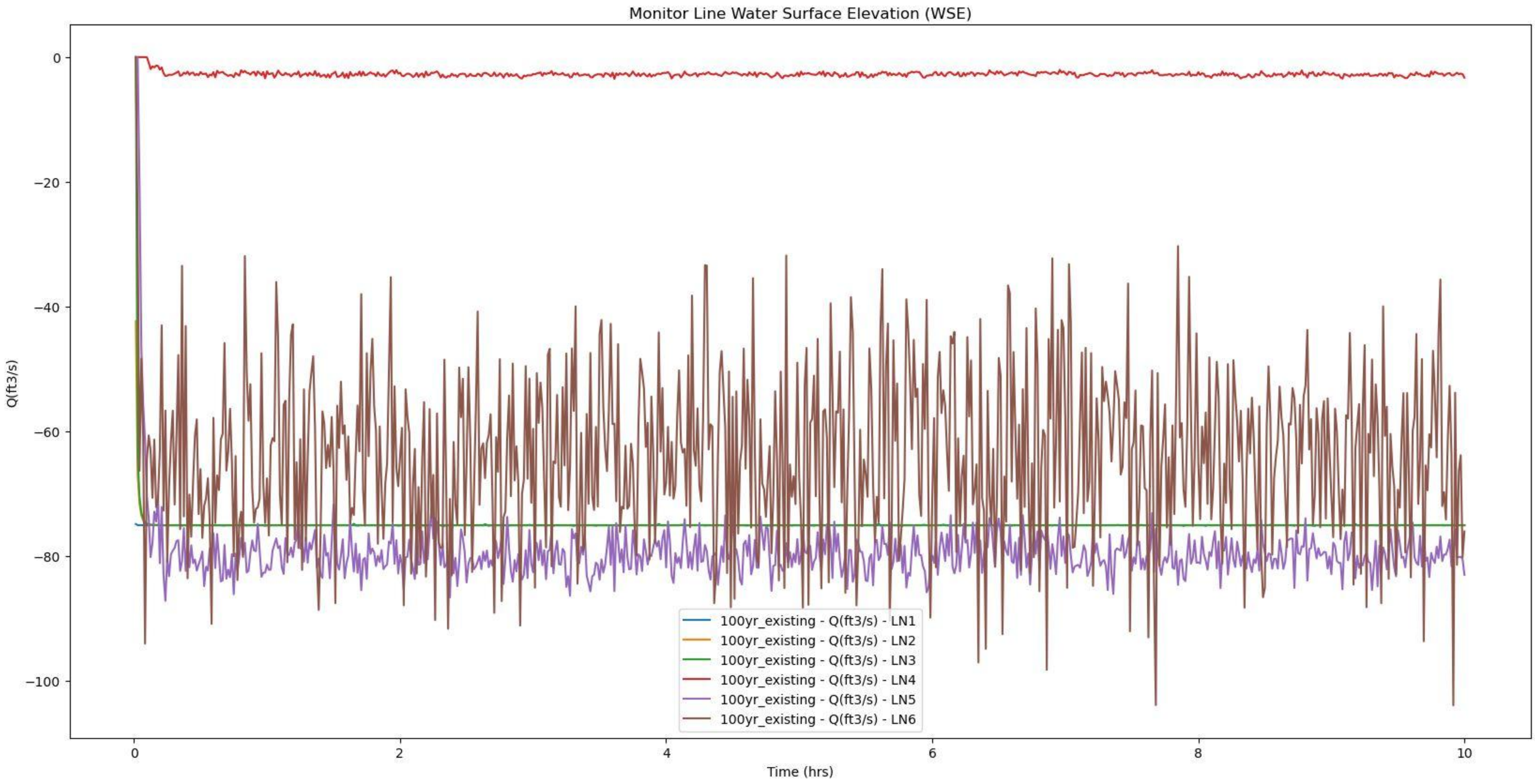


Figure I.5: Existing 100-year monitor lines

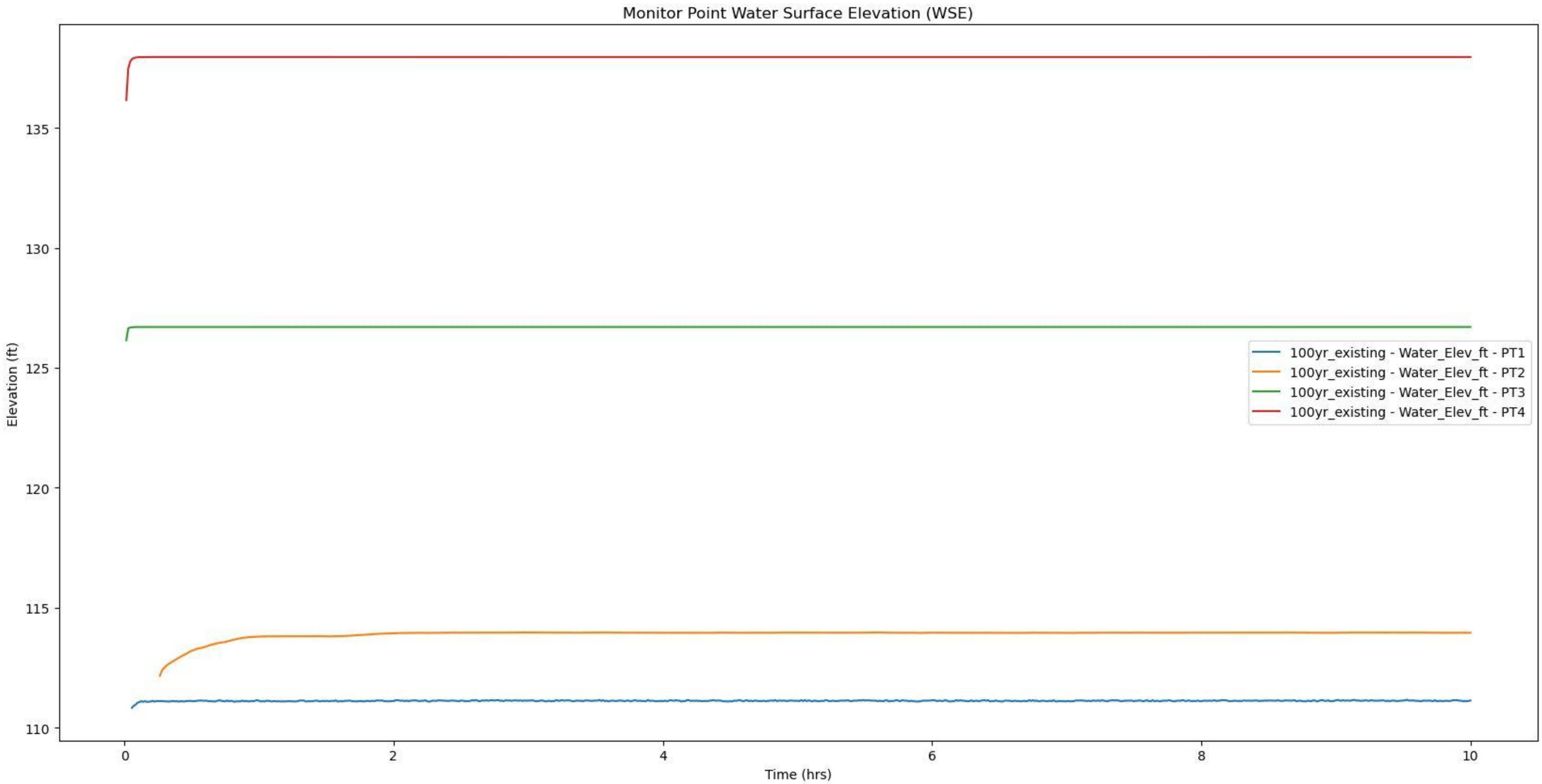


Figure I.6: Existing 100-year monitor points

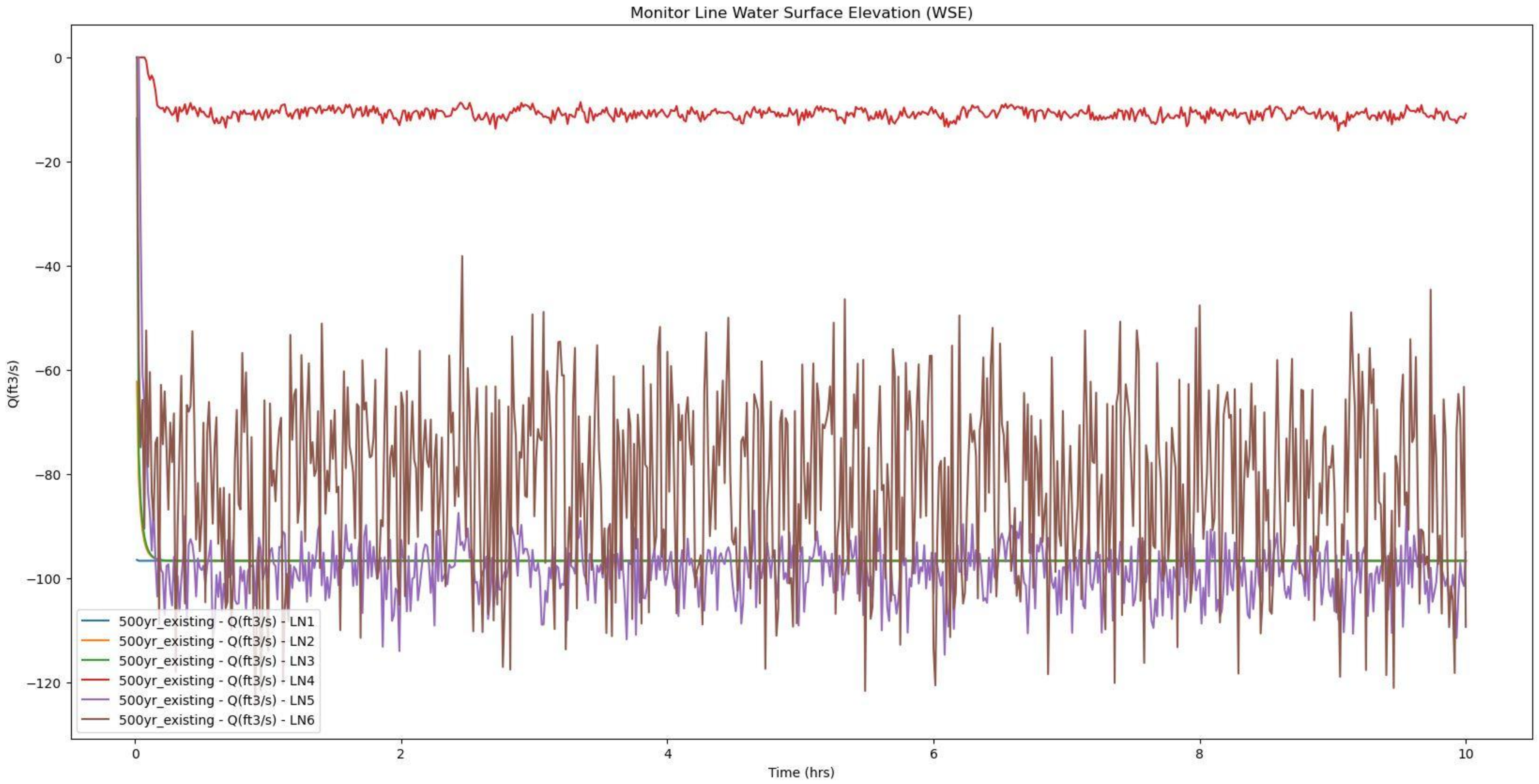


Figure I.7: Existing 500-year monitor lines

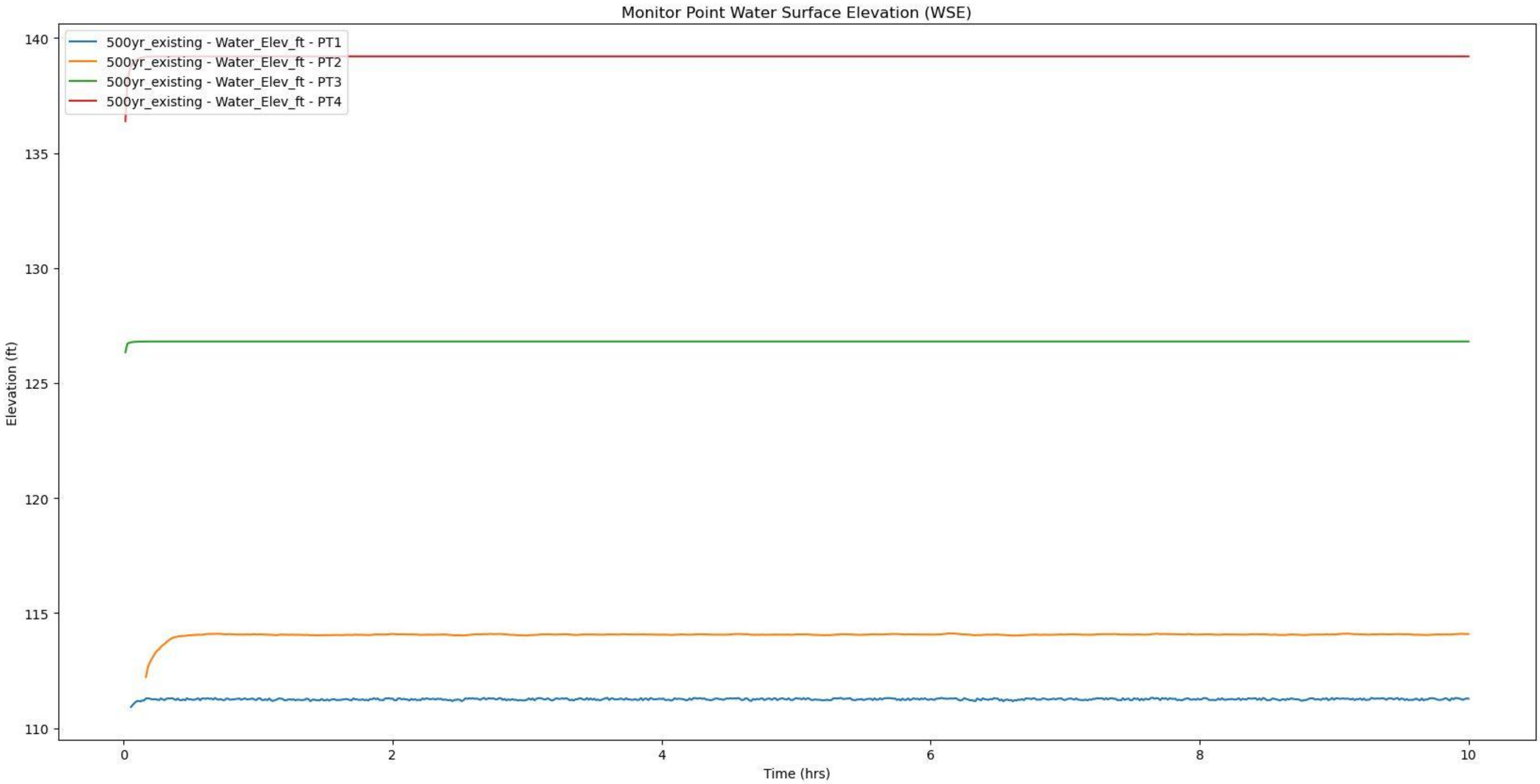


Figure I.8: Existing 500-year monitor points

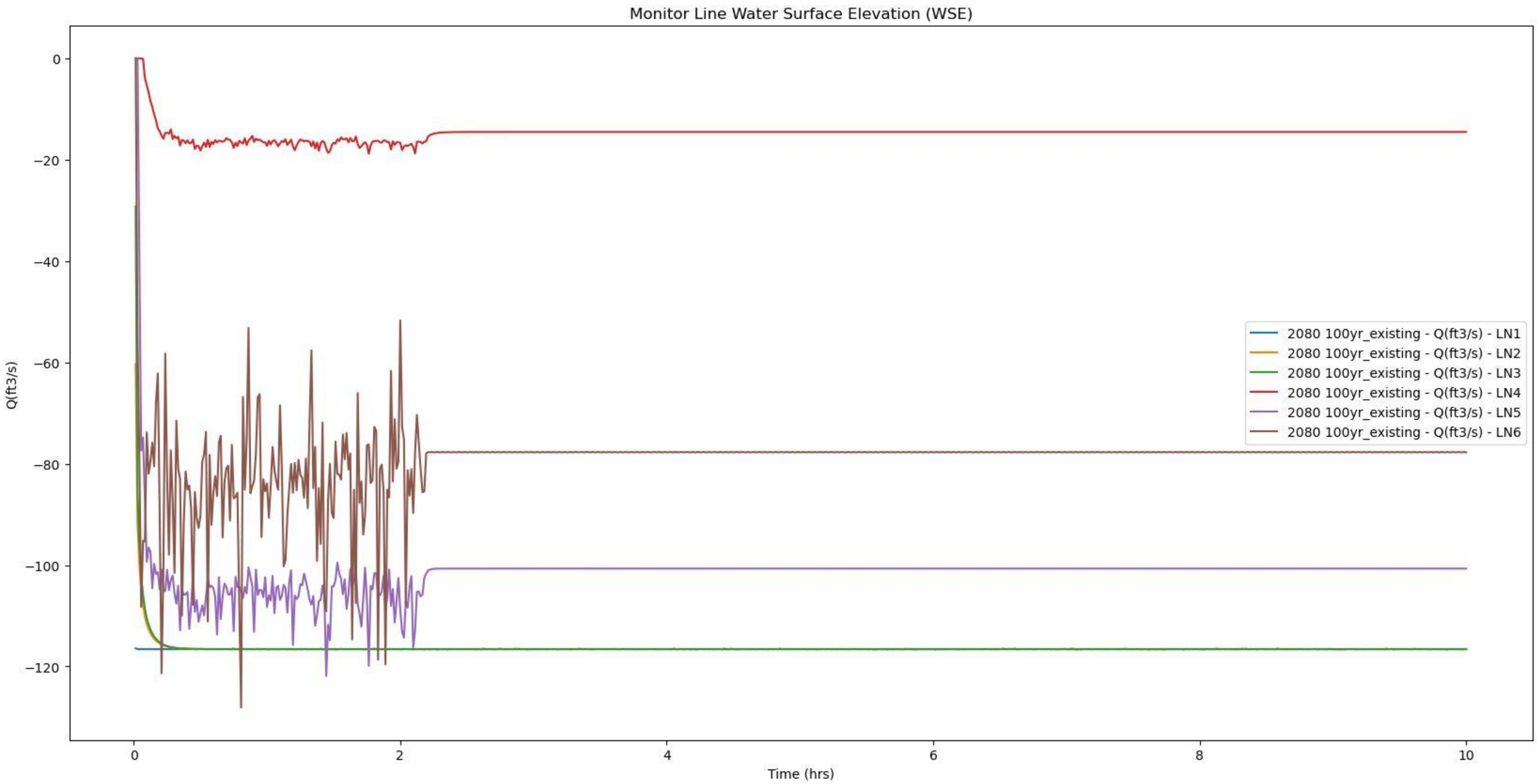


Figure I.9: Existing 2080 predicted 100-year monitor lines

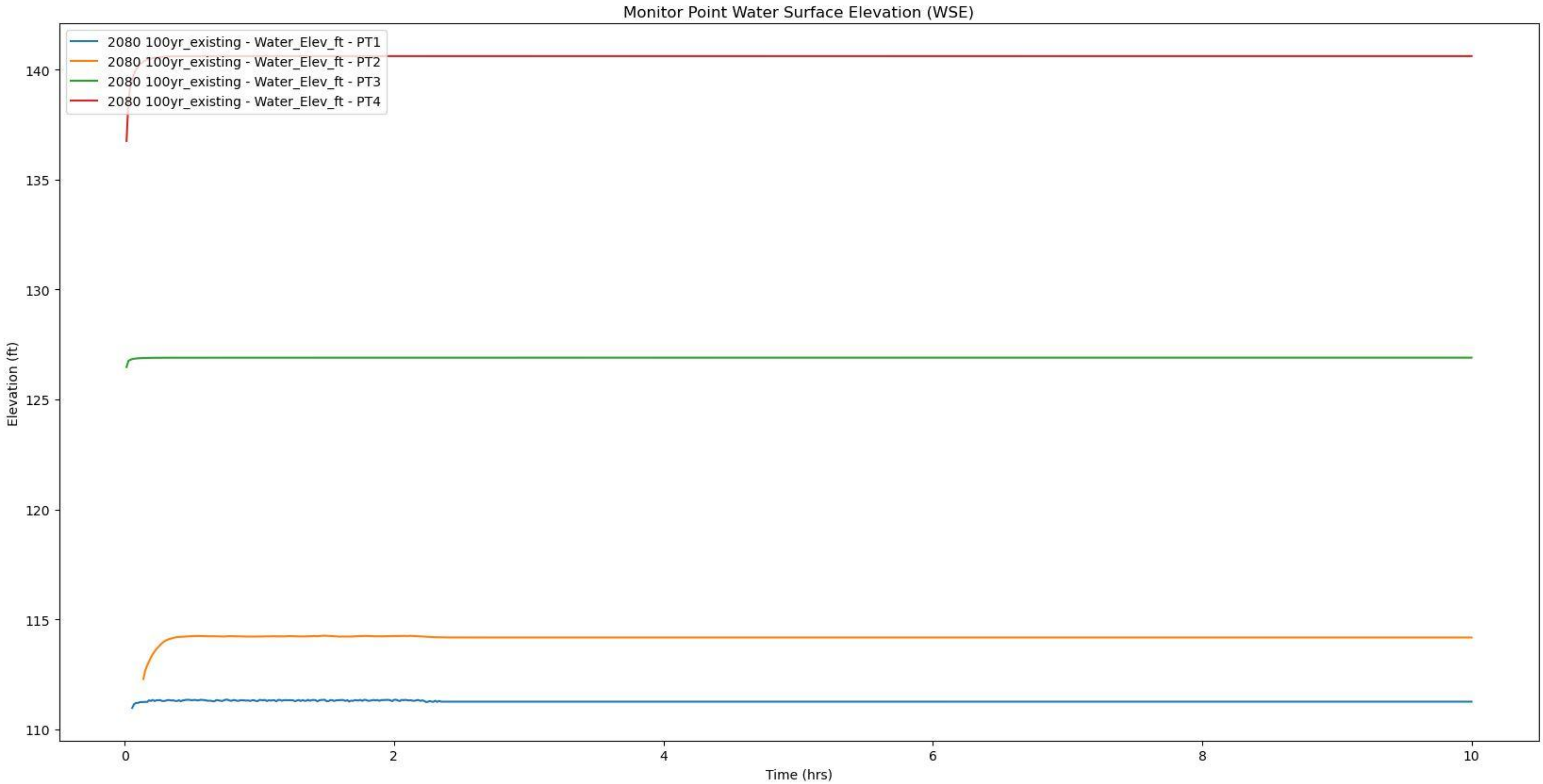


Figure I.10: Existing 2080 predicted 100-year monitor points

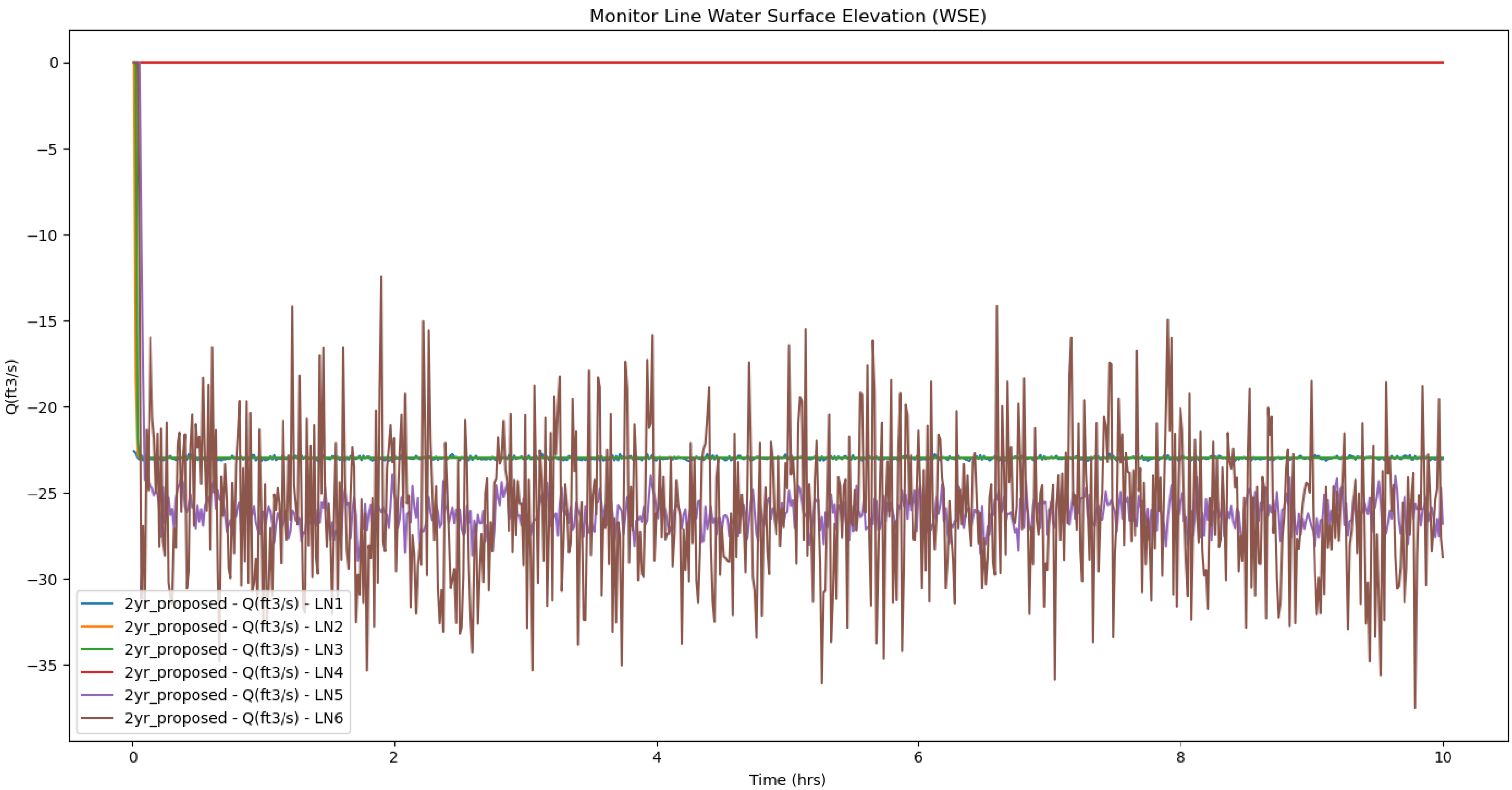


Figure I.11: Proposed 2-year monitor lines

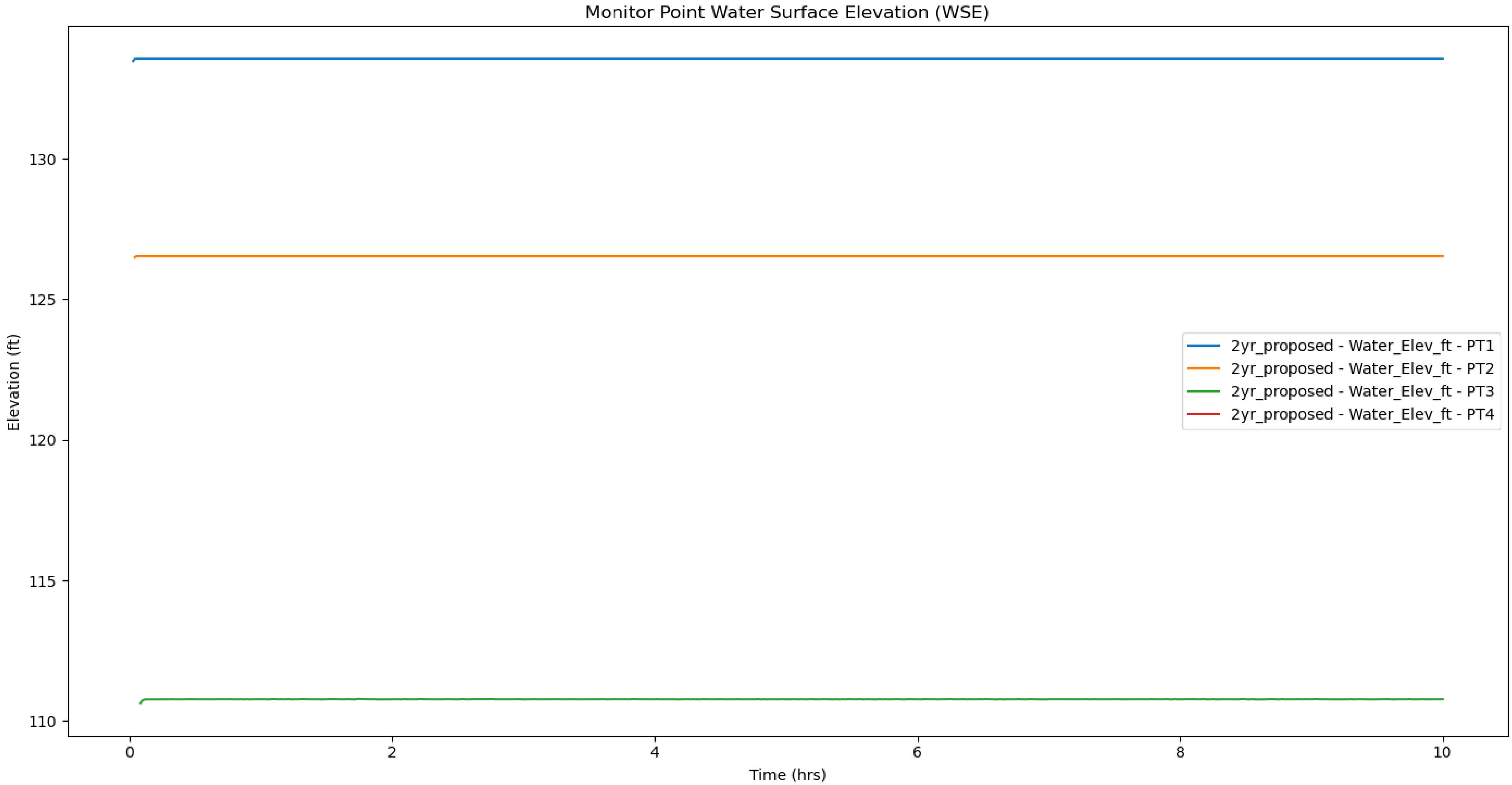


Figure I.12: Proposed 2-year monitor points

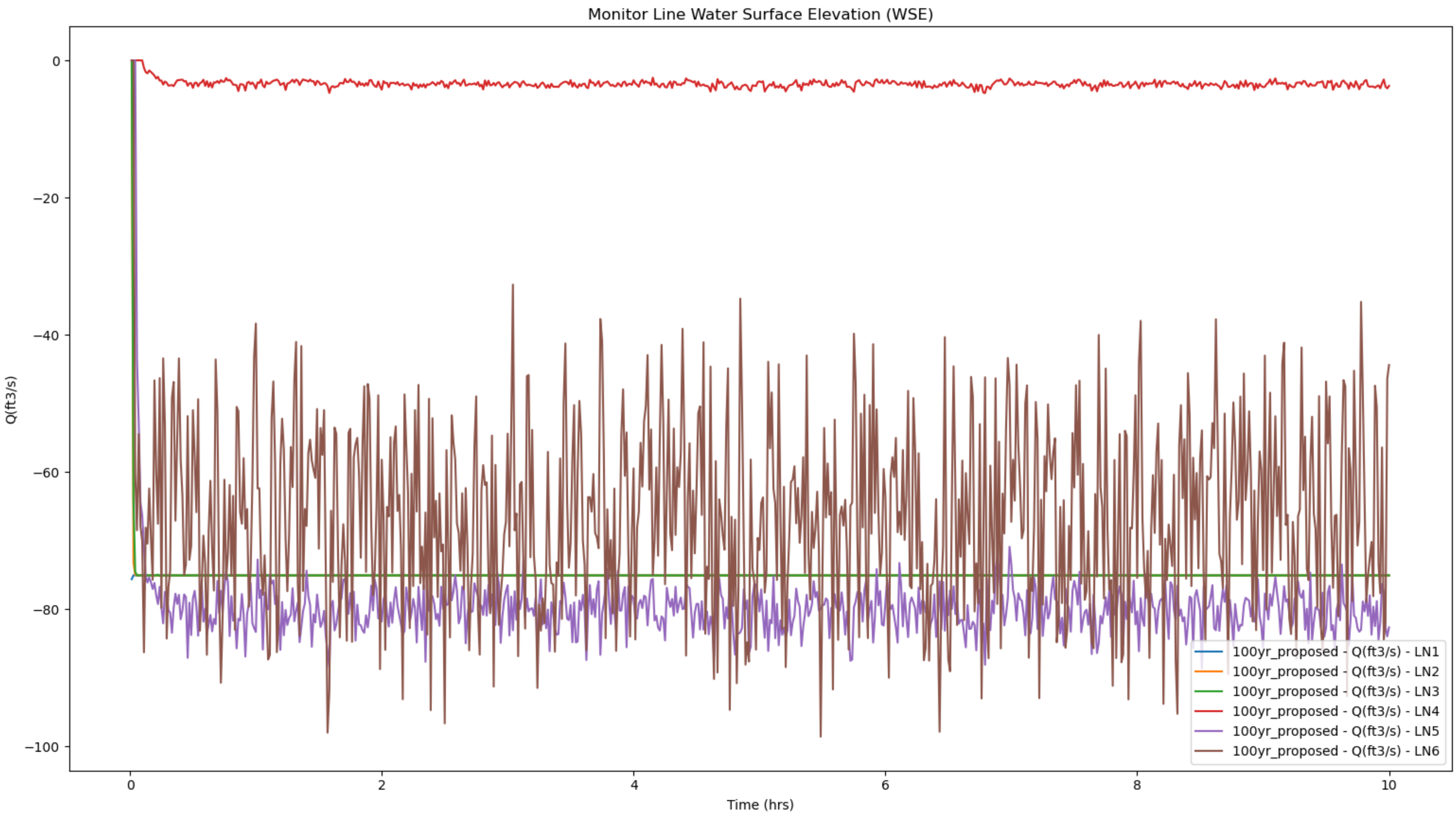


Figure I.13: Proposed 100-year monitor lines

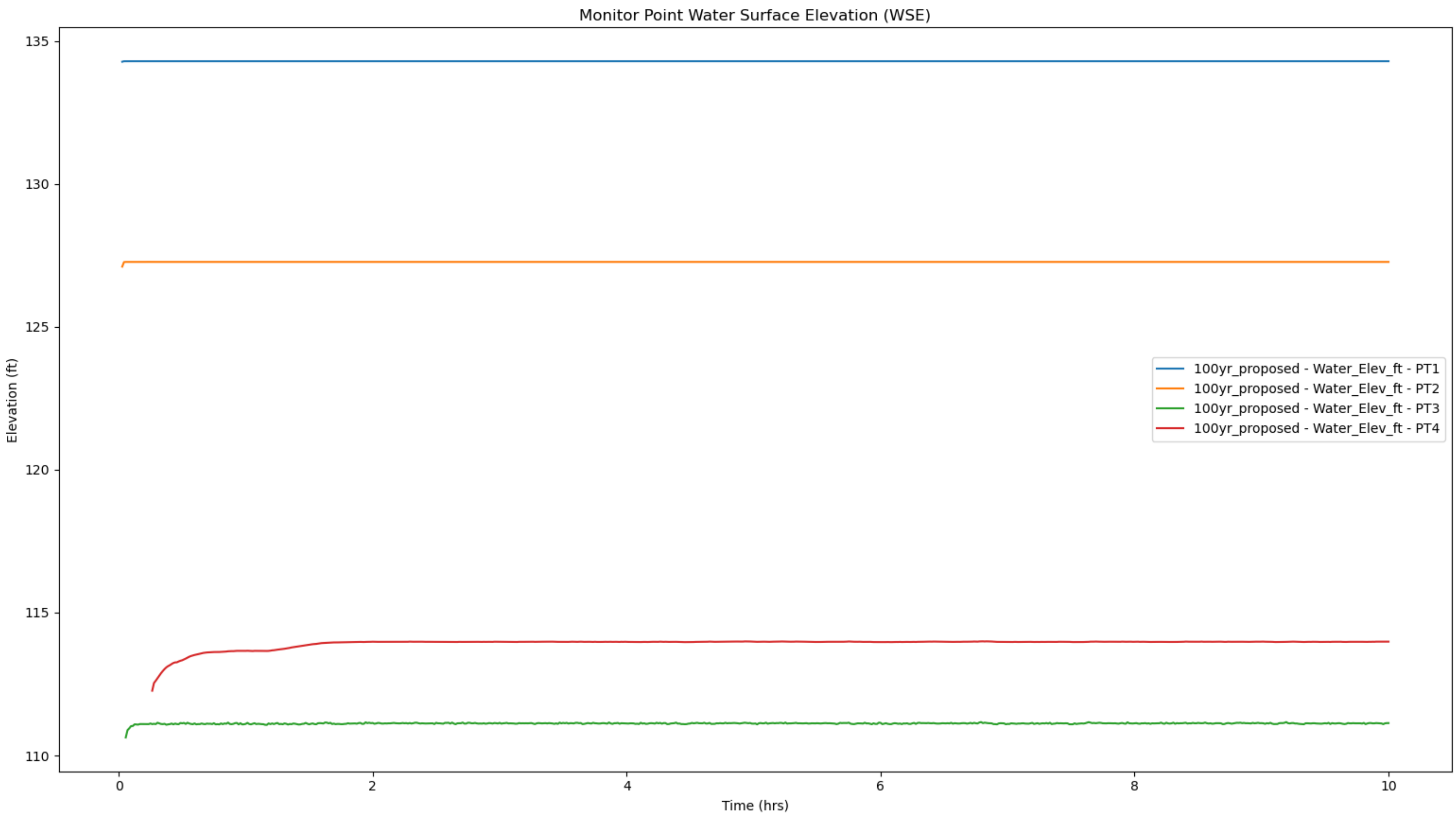


Figure I.14: Proposed 100-year monitor points

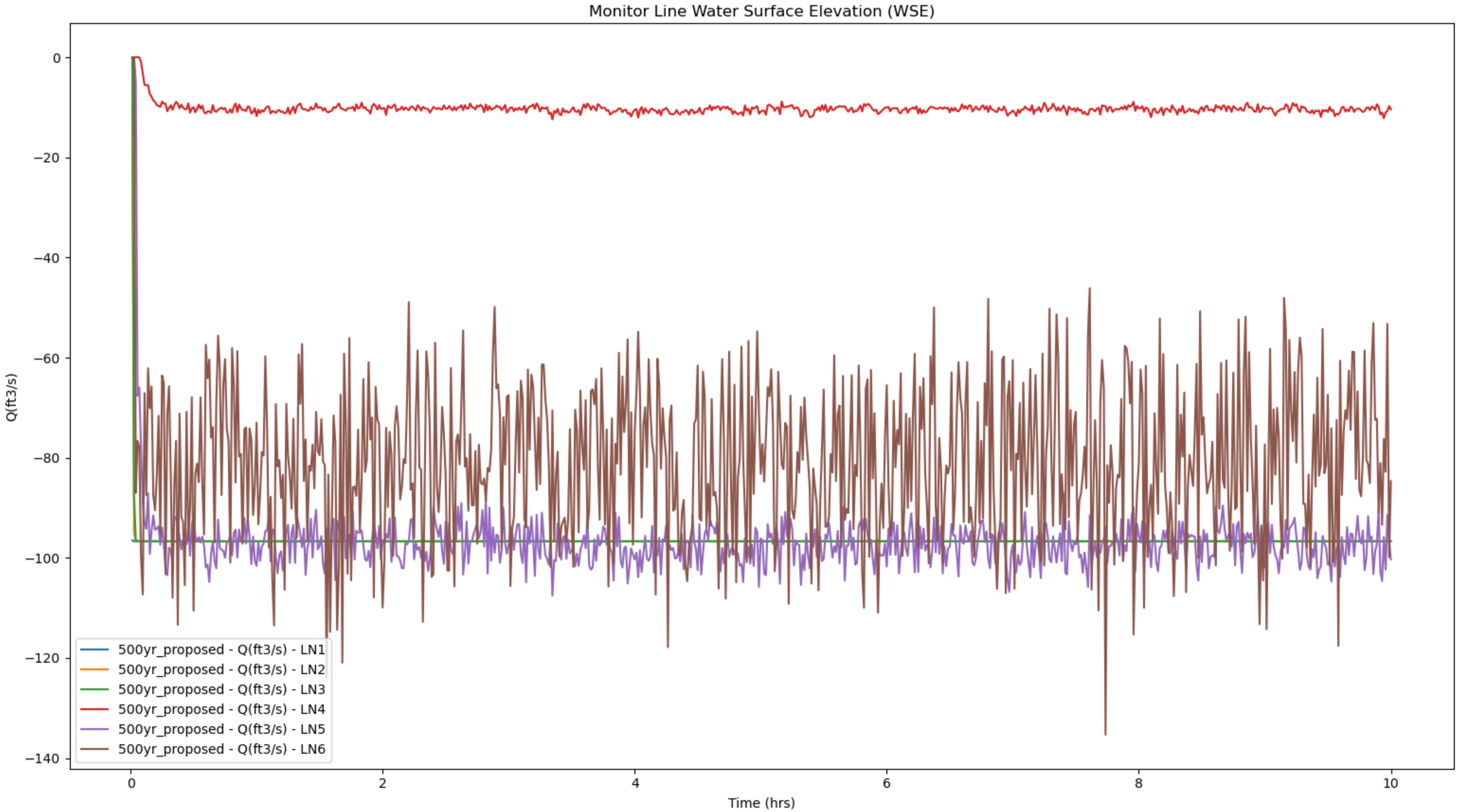


Figure I.15: Proposed 500-year monitor lines

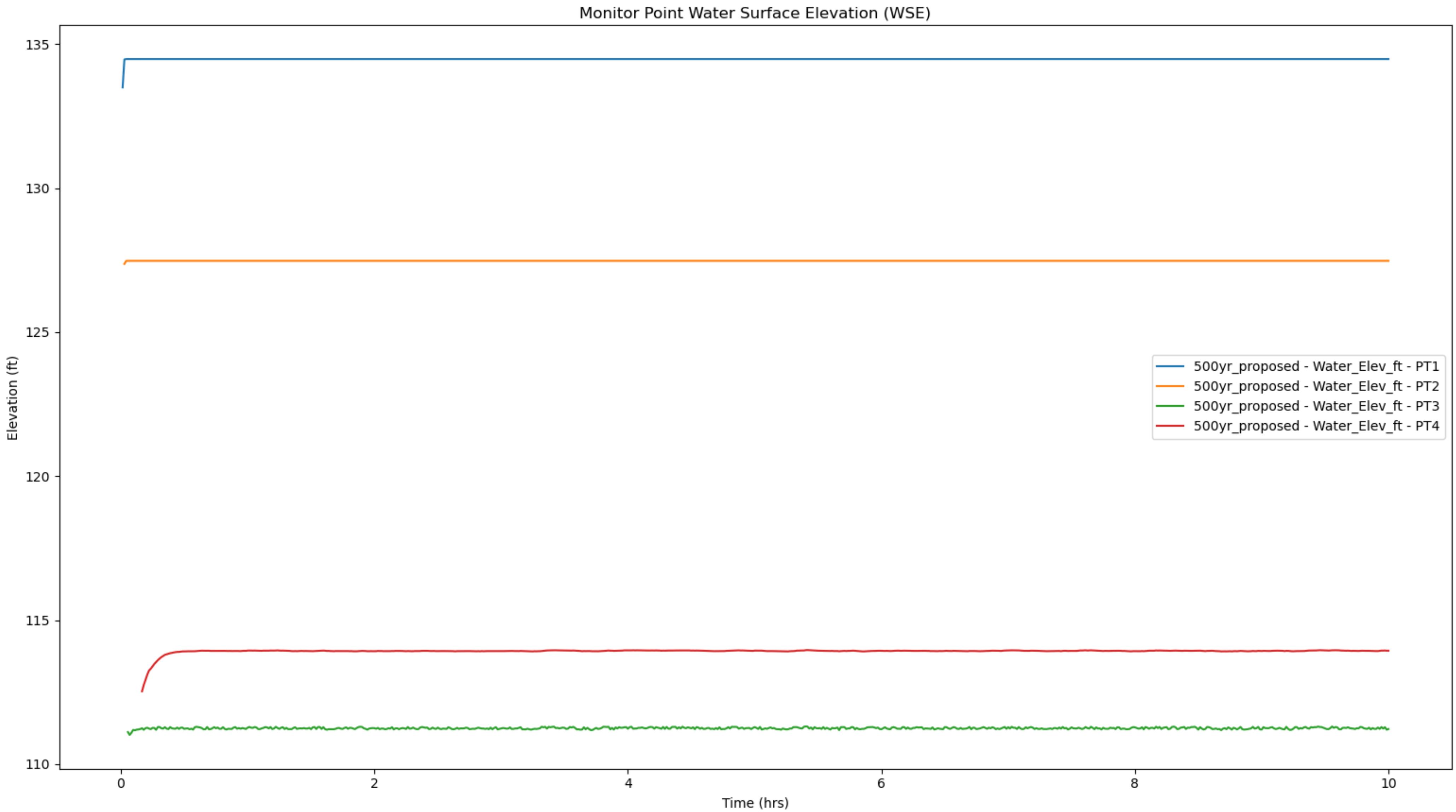


Figure I.16: Proposed 500-year monitor points

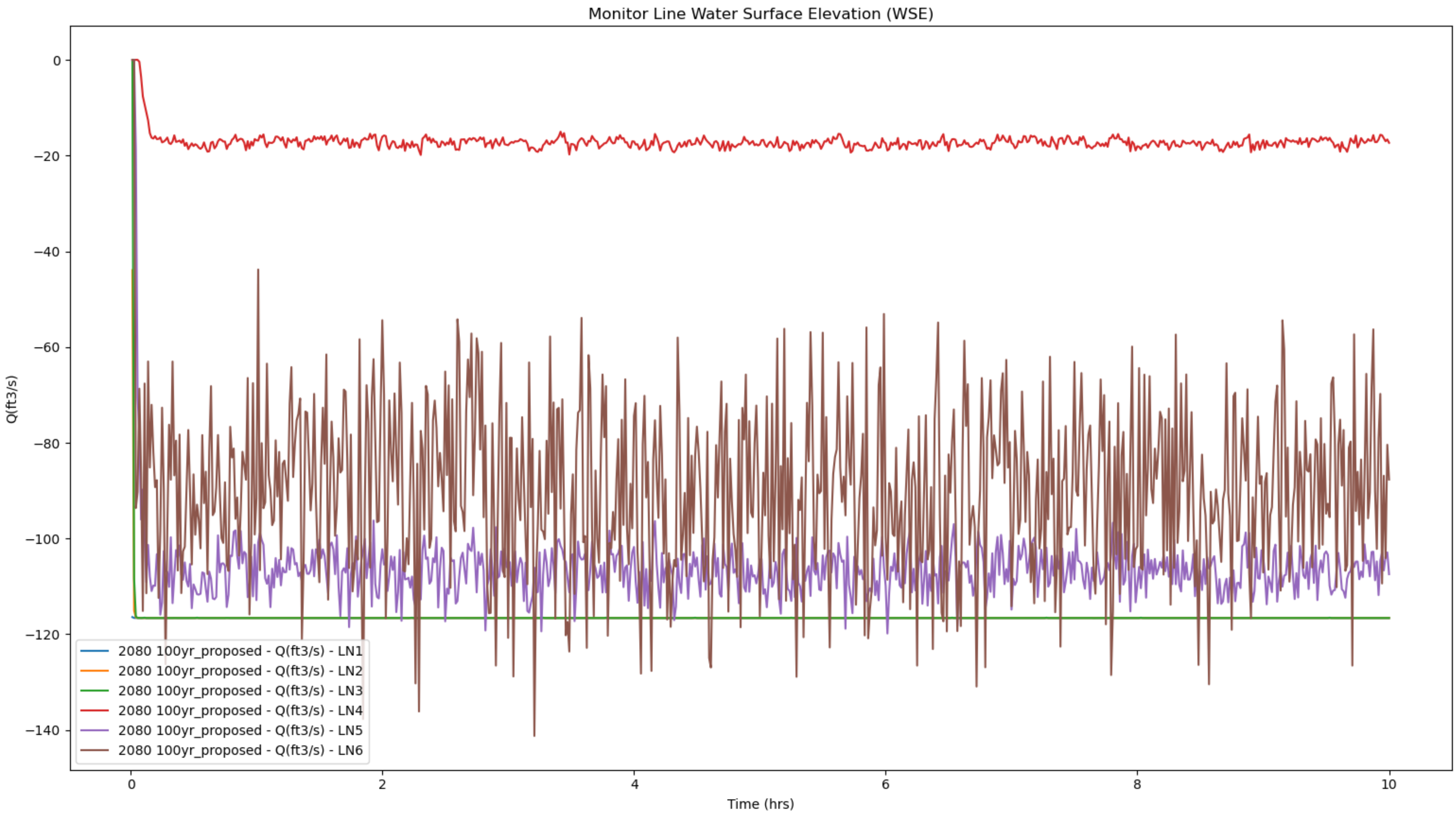


Figure I.17: Proposed 2080 predicted 100-year monitor lines

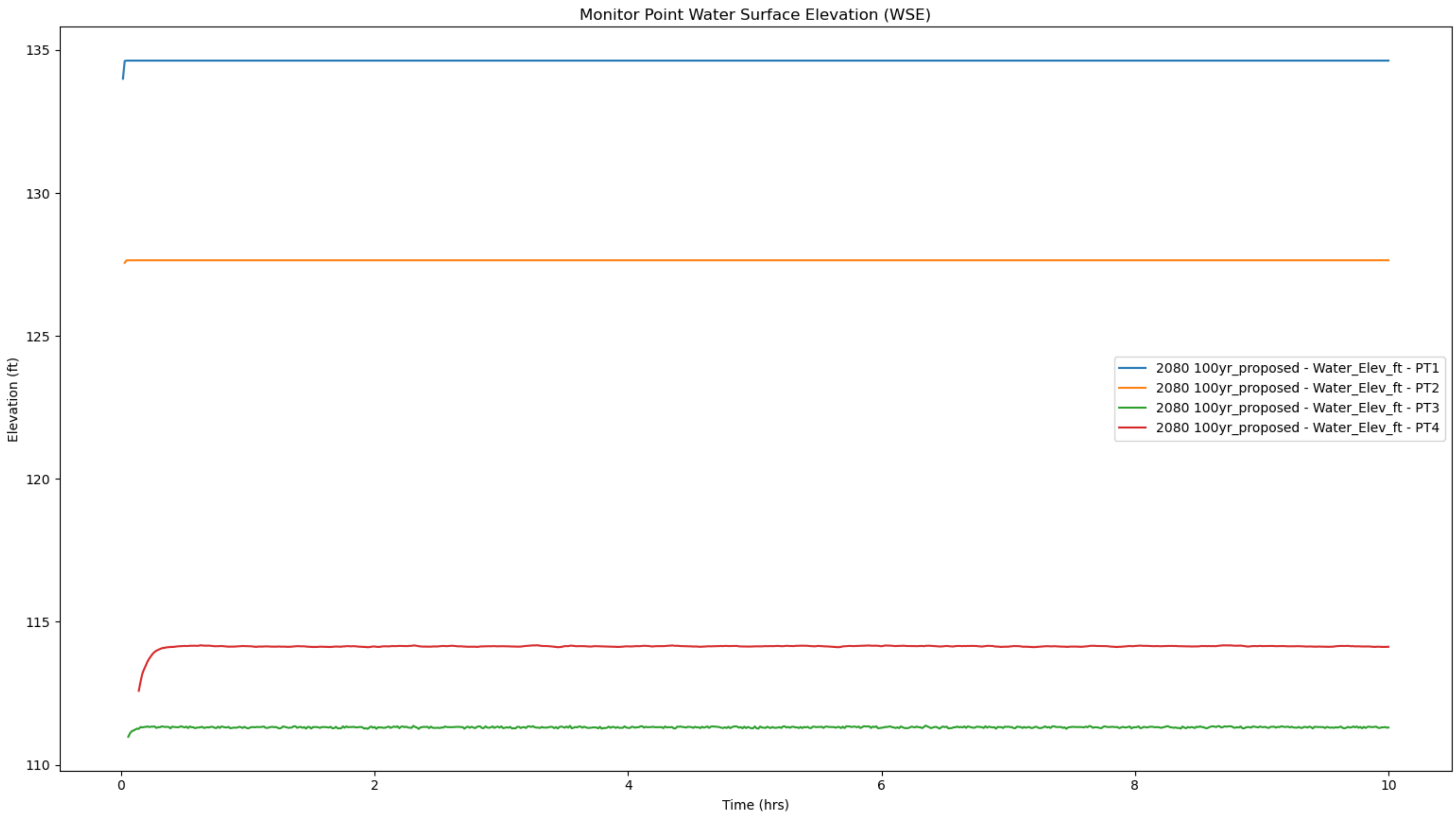


Figure I.18: Proposed 2080 predicted 100-year monitor lines

Appendix J: Reach Assessment

A reach assessment was not conducted for this site.

Appendix K: Scour Calculations

Hydraulic Analysis Report

Project Data

Project Title: Wildcat Creek

Designer:

Project Date: Thursday, February 3, 2022

Project Units: U.S. Customary Units

Notes:

Bridge Scour Analysis:EB Bridge 100-Year

Notes:

Scenario: SR 8_Wildcat_WB_100yr

Contraction Scour Summary

Contraction & Long Term Scour is applied method due to greater scour.

Live Bed Contraction Scour Depth 0.11 ft

Local Scour at Abutments Summary

Left Abutment

Abutment Scour Method: NCHRP Method

Abutment Scour Depth 0.29 ft

Total Scour at Abutment 0.29 ft

Main Channel Contraction Scour

Computation Type: Clear-Water and Live-Bed Scour

Input Parameters

Average Depth Upstream of Contraction: 1.50 ft

D50: 32.847991 mm

Average Velocity Upstream: 5.75 ft/s

Results of Scour Condition

Critical velocity above which bed material of size D and smaller will be transported: 5.69 ft/s

Contraction Scour Condition: Live-Bed

Live Bed and/or Clear Water Input Parameters

Temperature of Water: 40.00 ºF

Slope of Energy Grade Line at Approach Section: 0.0401 ft/ft

Flow in Contracted Section: 75.10 cfs

Flow Upstream that is Transporting Sediment: 75.10 cfs

Width in Contracted Section: 9.00 ft

Width Upstream that is Transporting Sediment: 9.00 ft

Depth Prior to Scour in Contracted Section: 1.39 ft

Unit Weight of Water: 62.40 lb/ft^3

Unit Weight of Sediment: 165.00 lb/ft^3

Results of Clear Water Method

Diameter of the smallest nontransportable particle in the bed material: 41.059989 mm

Average Depth in Contracted Section after Scour: 1.36 ft

Scour Depth: -0.03 ft

Results of Live Bed Method

Shear Velocity: 1.39 ft/s

Fall Velocity: 1.64 ft/s

Average Depth in Contracted Section after Scour: 1.50 ft

Scour Depth for Live Bed: 0.11 ft

Shear Applied to Bed by Live-Bed Scour: 0.5507 lb/ft^2

Shear Required for Movement of D50 Particle: 0.4312 lb/ft^2

Recommendations

Recommended Scour Depth: -0.03 ft

Left Abutment Details

Abutment Scour

Computation Type: NCHRP

Input Parameters

NCHRP Method

Abutment Type: Vertical-wall abutment

Angle of Embankment to Flow: 0.00 Degrees

Centerline Length of Embankment: 0.00 ft

Projected Length of Embankment: 0.00 ft

Width of Flood Plain: 0.00 ft

Unit Discharge, Upstream in Main Channel (q1): 8.34 cfs

Unit Discharge in the Constricted Area (q2): 8.34 cfs/ft

D50: 32.847991 mm

Upstream Flow Depth: 1.60 ft

Flow Depth Prior to Scour: 1.48 ft

Result Parameters

q2/q1: 1.00

Average Velocity Upstream: 5.21 ft/s

Critical Velocity above which Bed Materal of Size D and Smaller will be Transported: 5.75 ft/s

Scour Condition: Clear Water

Embankment Length/Floodplain Width Ratio: 0.00

Scour Condition: a (Main Channel)

Amplification Factor: 1.20

Flow Depth including Contraction Scour: 1.47 ft

Maximum Flow Depth including Abutment Scour: 1.77 ft

Scour Hole Depth from NCHRP Method: 0.29 ft

Bridge Scour Analysis:WB Bridge 100-Year

Notes:

Scenario: SR 8_Wildcat_WB_100yr

Contraction Scour Summary

Contraction & Long Term Scour is applied method due to greater scour.

Local Scour at Abutments Summary

Left Abutment

Abutment Scour Method: NCHRP Method

Abutment Scour Depth 0.25 ft

Total Scour at Abutment 0.25 ft

Main Channel Contraction Scour

Computation Type: Clear-Water and Live-Bed Scour

Input Parameters

Average Depth Upstream of Contraction: 1.50 ft

D50: 32.847991 mm

Average Velocity Upstream: 5.75 ft/s

Results of Scour Condition

Critical velocity above which bed material of size D and smaller will be transported: 5.69 ft/s

Contraction Scour Condition: Live-Bed

Live Bed and/or Clear Water Input Parameters

Temperature of Water: 40.00 ºF

Slope of Energy Grade Line at Approach Section: 0.0401 ft/ft

Flow in Contracted Section: 75.10 cfs

Flow Upstream that is Transporting Sediment: 75.10 cfs

Width in Contracted Section: 9.00 ft

Width Upstream that is Transporting Sediment: 9.00 ft

Depth Prior to Scour in Contracted Section: 1.52 ft

Unit Weight of Water: 62.40 lb/ft^3

Unit Weight of Sediment: 165.00 lb/ft^3

Results of Clear Water Method

Diameter of the smallest nontransportable particle in the bed material: 41.059989 mm

Average Depth in Contracted Section after Scour: 1.36 ft

Scour Depth: -0.16 ft

Results of Live Bed Method

Shear Velocity: 1.39 ft/s

Fall Velocity: 1.64 ft/s

Average Depth in Contracted Section after Scour: 1.50 ft

Scour Depth for Live Bed: -0.02 ft

Shear Applied to Bed by Live-Bed Scour: 0.5507 lb/ft^2

Shear Required for Movement of D50 Particle: 0.4312 lb/ft^2

Recommendations

Recommended Scour Depth: -0.16 ft

Left Abutment Details

Abutment Scour

Computation Type: NCHRP

Input Parameters

NCHRP Method

Abutment Type: Vertical-wall abutment

Angle of Embankment to Flow: 0.00 Degrees

Centerline Length of Embankment: 0.00 ft

Projected Length of Embankment: 0.00 ft

Width of Flood Plain: 0.00 ft

Unit Discharge, Upstream in Main Channel (q1): 8.34 cfs

Unit Discharge in the Constricted Area (q2): 8.34 cfs/ft

D50: 32.847991 mm

Upstream Flow Depth: 1.60 ft

Flow Depth Prior to Scour: 1.52 ft

Result Parameters
q2/q1: 1.00

Average Velocity Upstream: 5.21 ft/s

Critical Velocity above which Bed Material of Size D and Smaller will be Transported: 5.75 ft/s

Scour Condition: Clear Water

Embankment Length/Floodplain Width Ratio: 0.00

Scour Condition: a (Main Channel)

Amplification Factor: 1.20

Flow Depth including Contraction Scour: 1.47 ft

Maximum Flow Depth including Abutment Scour: 1.77 ft

Scour Hole Depth from NCHRP Method: 0.25 ft

Bridge Scour Analysis:EB Bridge 500-Year
Notes:

Scenario: Scour Scenario

Contraction Scour Summary
Contraction & Long Term Scour is applied method due to greater scour.

Applied Contraction Scour Depth 0.05 ft

Contraction & Long Term Scour is applied method due to greater scour.

Pressure Scour Depth 0.05 ft

Clear Water Contraction Scour Depth 0.05 ft

Live Bed Contraction Scour Depth 0.06 ft

Local Scour at Abutments Summary

Left Abutment
Abutment Scour Method: NCHRP Method

Abutment Scour Depth 0.19 ft

Total Scour at Abutment 0.19 ft

Main Channel Contraction Scour

Computation Type: Clear-Water and Live-Bed Scour

Input Parameters

Average Depth Upstream of Contraction: 1.70 ft

D50: 32.847991 mm

Average Velocity Upstream: 6.40 ft/s

Results of Scour Condition

Critical velocity above which bed material of size D and smaller will be transported: 5.81 ft/s

Contraction Scour Condition: Live-Bed

Live Bed and/or Clear Water Input Parameters

Temperature of Water: 40.00 ºF

Slope of Energy Grade Line at Approach Section: 0.0465 ft/ft

Flow in Contracted Section: 96.70 cfs

Flow Upstream that is Transporting Sediment: 96.70 cfs

Width in Contracted Section: 9.00 ft

Width Upstream that is Transporting Sediment: 9.00 ft

Depth Prior to Scour in Contracted Section: 1.64 ft

Unit Weight of Water: 62.40 lb/ft^3

Unit Weight of Sediment: 165.00 lb/ft^3

Results of Clear Water Method

Diameter of the smallest nontransportable particle in the bed material: 41.059989 mm

Average Depth in Contracted Section after Scour: 1.69 ft

Scour Depth: 0.05 ft

Results of Live Bed Method

Shear Velocity: 1.60 ft/s

Fall Velocity: 1.64 ft/s

Average Depth in Contracted Section after Scour: 1.70 ft

Scour Depth for Live Bed: 0.06 ft

Shear Applied to Bed by Live-Bed Scour: 0.7411 lb/ft^2

Shear Required for Movement of D50 Particle: 0.4312 lb/ft^2

Recommendations

Recommended Scour Depth: 0.05 ft

Left Abutment Details

Abutment Scour

Computation Type: NCHRP

Input Parameters

NCHRP Method

Abutment Type: Vertical-wall abutment

Angle of Embankment to Flow: 0.00 Degrees

Centerline Length of Embankment: 0.00 ft

Projected Length of Embankment: 0.00 ft

Width of Flood Plain: 0.00 ft

Unit Discharge, Upstream in Main Channel (q1): 10.74 cfs

Unit Discharge in the Constricted Area (q2): 10.74 cfs/ft

D50: 32.847991 mm

Upstream Flow Depth: 1.80 ft

Flow Depth Prior to Scour: 1.64 ft

Result Parameters

q2/q1: 1.00

Average Velocity Upstream: 5.97 ft/s

Critical Velocity above which Bed Materal of Size D and Smaller will be Transported: 5.86 ft/s

Scour Condition: Live Bed

Embankment Length/Floodplain Width Ratio: 0.00

Scour Condition: a (Main Channel)

Amplification Factor: 1.20

Flow Depth including Contraction Scour: 1.83 ft

Maximum Flow Depth including Abutment Scour: 1.83 ft

Scour Hole Depth from NCHRP Method: 0.19 ft

Bridge Scour Analysis:WB Bridge 500-Year

Notes:

Scenario: Scour Scenario

Contraction Scour Summary

Contraction & Long Term Scour is applied method due to greater scour.

Live Bed Contraction Scour Depth 0.01 ft

Local Scour at Abutments Summary

Left Abutment

Abutment Scour Method: NCHRP Method

Abutment Scour Depth 0.14 ft

Total Scour at Abutment 0.14 ft

Main Channel Contraction Scour

Computation Type: Clear-Water and Live-Bed Scour

Input Parameters

Average Depth Upstream of Contraction: 1.70 ft

D50: 32.847991 mm

Average Velocity Upstream: 6.40 ft/s

Results of Scour Condition

Critical velocity above which bed material of size D and smaller will be transported: 5.81 ft/s

Contraction Scour Condition: Live-Bed

Live Bed and/or Clear Water Input Parameters

Temperature of Water: 40.00 ºF

Slope of Energy Grade Line at Approach Section: 0.0465 ft/ft

Flow in Contracted Section: 96.70 cfs

Flow Upstream that is Transporting Sediment: 96.70 cfs

Width in Contracted Section: 9.00 ft

Width Upstream that is Transporting Sediment: 9.00 ft

Depth Prior to Scour in Contracted Section: 1.69 ft

Unit Weight of Water: 62.40 lb/ft^3

Unit Weight of Sediment: 165.00 lb/ft^3

Results of Clear Water Method

Diameter of the smallest nontransportable particle in the bed material: 41.059989 mm

Average Depth in Contracted Section after Scour: 1.69 ft

Scour Depth: -0.00 ft

Results of Live Bed Method

Shear Velocity: 1.60 ft/s

Fall Velocity: 1.64 ft/s

Average Depth in Contracted Section after Scour: 1.70 ft

Scour Depth for Live Bed: 0.01 ft

Shear Applied to Bed by Live-Bed Scour: 0.7411 lb/ft^2

Shear Required for Movement of D50 Particle: 0.4312 lb/ft^2

Recommendations

Recommended Scour Depth: -0.00 ft

Left Abutment Details

Abutment Scour

Computation Type: NCHRP

Input Parameters

NCHRP Method

Abutment Type: Vertical-wall abutment

Angle of Embankment to Flow: 0.00 Degrees

Centerline Length of Embankment: 0.00 ft

Projected Length of Embankment: 0.00 ft

Width of Flood Plain: 0.00 ft

Unit Discharge, Upstream in Main Channel (q1): 10.74 cfs

Unit Discharge in the Constricted Area (q2): 10.74 cfs/ft

D50: 32.847991 mm

Upstream Flow Depth: 1.80 ft

Flow Depth Prior to Scour: 1.69 ft

Result Parameters

q2/q1: 1.00

Average Velocity Upstream: 5.97 ft/s

Critical Velocity above which Bed Materal of Size D and Smaller will be Transported: 5.86 ft/s

Scour Condition: Live Bed

Embankment Length/Floodplain Width Ratio: 0.00

Scour Condition: a (Main Channel)

Amplification Factor: 1.20

Flow Depth including Contraction Scour: 1.83 ft

Maximum Flow Depth including Abutment Scour: 1.83 ft

Scour Hole Depth from NCHRP Method: 0.14 ft

Bridge Scour Analysis:EB Bridge 2080 100-Year

Notes:

Scenario: Scour Scenario

Contraction Scour Summary

Contraction & Long Term Scour is applied method due to greater scour.

Applied Contraction Scour Depth 0.09 ft

Contraction & Long Term Scour is applied method due to greater scour.

Pressure Scour Depth 0.09 ft

Clear Water Contraction Scour Depth 0.22 ft

Live Bed Contraction Scour Depth 0.09 ft

Local Scour at Abutments Summary

Left Abutment

Abutment Scour Method: NCHRP Method

Abutment Scour Depth 0.39 ft

Total Scour at Abutment 0.39 ft

Main Channel Contraction Scour

Computation Type: Clear-Water and Live-Bed Scour

Input Parameters

Average Depth Upstream of Contraction: 1.85 ft

D50: 32.847991 mm

Average Velocity Upstream: 6.95 ft/s

Results of Scour Condition

Critical velocity above which bed material of size D and smaller will be transported: 5.89 ft/s

Contraction Scour Condition: Live-Bed

Live Bed and/or Clear Water Input Parameters

Temperature of Water: 40.00 ºF

Slope of Energy Grade Line at Approach Section: 0.0447 ft/ft

Flow in Contracted Section: 116.60 cfs

Flow Upstream that is Transporting Sediment: 116.60 cfs

Width in Contracted Section: 9.00 ft

Width Upstream that is Transporting Sediment: 9.00 ft

Depth Prior to Scour in Contracted Section: 1.76 ft

Unit Weight of Water: 62.40 lb/ft^3

Unit Weight of Sediment: 165.00 lb/ft^3

Results of Clear Water Method

Diameter of the smallest nontransportable particle in the bed material: 41.059989 mm

Average Depth in Contracted Section after Scour: 1.98 ft

Scour Depth: 0.22 ft

Results of Live Bed Method

Shear Velocity: 1.63 ft/s

Fall Velocity: 1.64 ft/s

Average Depth in Contracted Section after Scour: 1.85 ft

Scour Depth for Live Bed: 0.09 ft

Shear Applied to Bed by Live-Bed Scour: 0.9359 lb/ft^2

Shear Required for Movement of D50 Particle: 0.4312 lb/ft^2

Recommendations

Recommended Scour Depth: 0.09 ft

Left Abutment Details

Abutment Scour

Computation Type: NCHRP

Input Parameters

NCHRP Method

Abutment Type: Vertical-wall abutment

Angle of Embankment to Flow: 0.00 Degrees

Centerline Length of Embankment: 0.00 ft

Projected Length of Embankment: 0.00 ft

Width of Flood Plain: 0.00 ft

Unit Discharge, Upstream in Main Channel (q1): 12.96 cfs

Unit Discharge in the Constricted Area (q2): 12.96 cfs/ft

D50: 32.847991 mm

Upstream Flow Depth: 1.96 ft

Flow Depth Prior to Scour: 1.76 ft

Result Parameters

q2/q1: 1.00

Average Velocity Upstream: 6.61 ft/s

Critical Velocity above which Bed Materal of Size D and Smaller will be Transported: 5.95 ft/s

Scour Condition: Live Bed

Embankment Length/Floodplain Width Ratio: 0.00

Scour Condition: a (Main Channel)

Amplification Factor: 1.20

Flow Depth including Contraction Scour: 2.15 ft

Maximum Flow Depth including Abutment Scour: 2.15 ft

Scour Hole Depth from NCHRP Method: 0.39 ft

Bridge Scour Analysis:WB Bridge 2080 100-Year

Notes:

Scenario: Scour Scenario

Contraction Scour Summary

Contraction & Long Term Scour is applied method due to greater scour.

Applied Contraction Scour Depth 0.03 ft

Contraction & Long Term Scour is applied method due to greater scour.

Pressure Scour Depth 0.03 ft

Clear Water Contraction Scour Depth 0.16 ft

Live Bed Contraction Scour Depth 0.03 ft

Local Scour at Abutments Summary

Left Abutment

Abutment Scour Method: NCHRP Method

Abutment Scour Depth 0.33 ft

Total Scour at Abutment 0.33 ft

Main Channel Contraction Scour

Computation Type: Clear-Water and Live-Bed Scour

Input Parameters

Average Depth Upstream of Contraction: 1.85 ft

D50: 32.847991 mm

Average Velocity Upstream: 6.95 ft/s

Results of Scour Condition

Critical velocity above which bed material of size D and smaller will be transported: 5.89 ft/s

Contraction Scour Condition: Live-Bed

Live Bed and/or Clear Water Input Parameters

Temperature of Water: 40.00 ºF

Slope of Energy Grade Line at Approach Section: 0.0447 ft/ft

Flow in Contracted Section: 116.60 cfs

Flow Upstream that is Transporting Sediment: 116.60 cfs

Width in Contracted Section: 9.00 ft

Width Upstream that is Transporting Sediment: 9.00 ft

Depth Prior to Scour in Contracted Section: 1.82 ft

Unit Weight of Water: 62.40 lb/ft^3

Unit Weight of Sediment: 165.00 lb/ft^3

Results of Clear Water Method

Diameter of the smallest nontransportable particle in the bed material: 41.059989 mm

Average Depth in Contracted Section after Scour: 1.98 ft

Scour Depth: 0.16 ft

Results of Live Bed Method

Shear Velocity: 1.63 ft/s

Fall Velocity: 1.64 ft/s

Average Depth in Contracted Section after Scour: 1.85 ft

Scour Depth for Live Bed: 0.03 ft

Shear Applied to Bed by Live-Bed Scour: 0.9359 lb/ft^2

Shear Required for Movement of D50 Particle: 0.4312 lb/ft^2

Recommendations

Recommended Scour Depth: 0.03 ft

Left Abutment Details

Abutment Scour

Computation Type: NCHRP

Input Parameters

NCHRP Method

Abutment Type: Vertical-wall abutment

Angle of Embankment to Flow: 0.00 Degrees

Centerline Length of Embankment: 0.00 ft

Projected Length of Embankment: 0.00 ft

Width of Flood Plain: 0.00 ft

Unit Discharge, Upstream in Main Channel (q1): 12.96 cfs

Unit Discharge in the Constricted Area (q2): 12.96 cfs/ft

D50: 32.847991 mm

Upstream Flow Depth: 1.96 ft

Flow Depth Prior to Scour: 1.82 ft

Result Parameters

q2/q1: 1.00

Average Velocity Upstream: 6.61 ft/s

Critical Velocity above which Bed Materal of Size D and Smaller will be Transported: 5.95 ft/s

Scour Condition: Live Bed

Embankment Length/Floodplain Width Ratio: 0.00

Scour Condition: a (Main Channel)

Amplification Factor: 1.20

Flow Depth including Contraction Scour: 2.15 ft

Maximum Flow Depth including Abutment Scour: 2.15 ft

Scour Hole Depth from NCHRP Method: 0.33 ft

Appendix L: Floodplain Analysis

Because this site is not located in a FEMA floodplain, no floodplain analysis was completed.

Appendix M: Scour Countermeasure Calculations

DAVID EVANS AND ASSOCIATES INC.

JOB DESCRIPTION Wildcat Creek

CALCULATION FOR riprap size

Ref. HEC - No. 23 (2009)
Eq 14.1 for Froude Numbers < 0.80

$$\frac{D_{50}}{y} = \frac{K}{(S_s - 1)}\left[\frac{V^2}{gy}\right]$$

Set back length (ft)	31
Channel flow depth (ft)	1.5
SBR	20.67
if SBR > 5, use only overbank flow	
Q (overbank) (cfs)	0.19
A (overbank) (ft^2)	0.37
Q/A (ft/s)	0.51
Q (channel) (cfs)	74.12
A (channel) (ft^2)	10.03
Q/A (ft/s)	7.39
Velocity that will be used (ft/s)	0.51
Froude Number	0.07
K	1.02
(0.89 for spill-though abutment)	
(1.02 for vertical wall abutment)	
D50 (ft)	**0.005**
D50 (in)	**0.061**